Sction 1 Table of Contents

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List of Illustrations

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SECTION 1 - 50 YEARS OF HUMAN ENGINEERING: NARRATIVE HISTORY

I. ORGANIZATION, MISSION, AND GOALS

The Fitts Human Engineering Division is one of three research divisions within the Crew Systems Directorate of the Armstrong Laboratory, headquartered at Brooks Air Force Base, San Antonio, Texas (Figure 1-1). The mission of the Fitts Human Engineering Division is to enable or ensure the effective integration of humans with technology in USAF systems. Research and Development (R&D) is directed at boosting system performance and affordability by enhancing the operability, supportability, and survivability of these complex human systems. The scope of the R&D program encompasses three areas of regard:

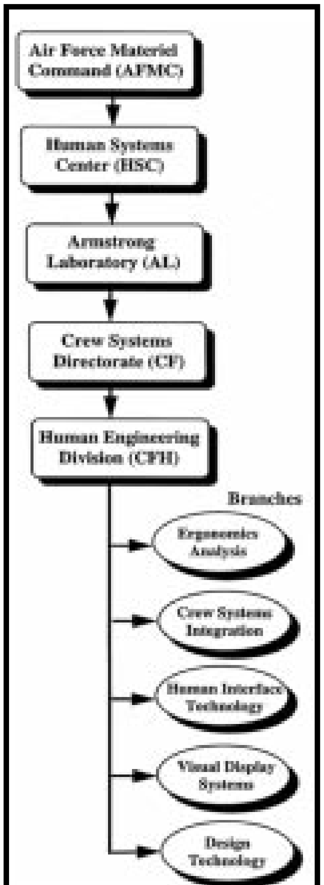

FIGURE 1-1: ORGANIZATIONAL CHART

(1) **Information Management & Display** develops methods and media to ensure reliable access to and decision making with task critical information by individuals, teams, and organizations;

(2) **Performance Aiding** produces innovative technologies for assisting operators and maintainers in performing their jobs more effectively, thereby minimizing human error while optimizing speed and quality of mission performance; and,

(3) **Design Integration** advances specialized databases, metrics, tools, and models of human capabilities and attributes to ensure that equipment designs support the fullest potential of warfighters, irrespective of gender, mission, or environment.

R&D in each of these technical problem areas may be conducted under the core program or as a rapid response to customer requirements. The latter activity, analogous to "fire-fighting," is characterized by short-suspense problem-solving "in the field" using the best data, knowledge, and skills that are readily available (Figure 1-2) . This activity has typically encompassed consulting and trouble-shooting of human factors problems with military equipment during design, integration, test and evaluation, and deployment or operations in varying stages of the acquisition process or in the field. Increasingly, this "fire-fighting" activity includes response to commercial industry, academia, local government, and other federal agencies. Most of these efforts are directly funded or cost-reimbursed by customers and, in recent years, have encompassed approximately 30 percent of the total activity of the division. This work has been especially vital to maintaining the relevance of our overall R&D program to USAF and military needs.

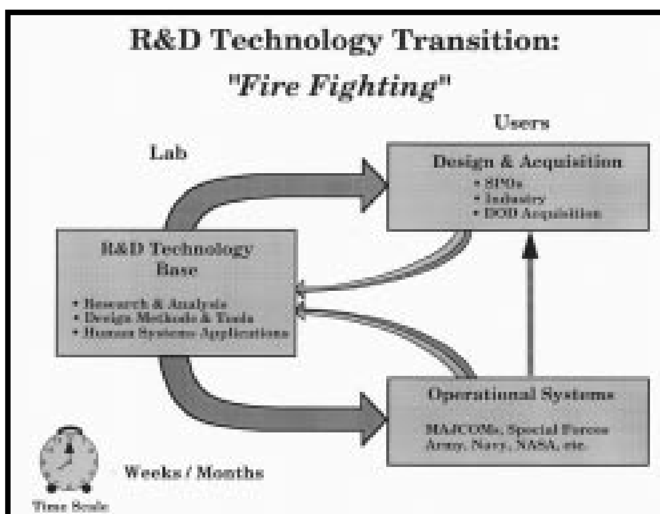

FIGURE 1-2: FIRE FIGHTING

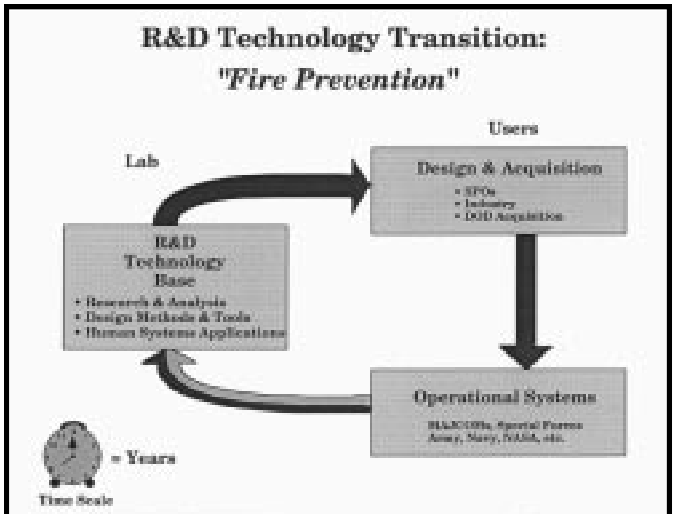

FIGURE 1-3: FIRE PREVENTION

Human Engineering Division Facilities

Design Technology Laboratories
- Behavioral Visualization Laboratory
- Crew-Centered Analysis and Design Support Laboratory (C-CADS)
- Computerized Anthropometric Research and Design Laboratories (CARD)
- Physical Ergonomics Laboratory (PEL)

Crew Systems Integration
- Multi-Operator Design Assessment Laboratory
- Crew Aiding and Information Warfare Analysis Laboratory (CIWAL)

Operator Assessment Technologies
- Cognitive Assessment Laboratory (CAL)
- Flight Psychophysiology Laboratory

Adaptive Interface Technologies
- Synthesized Immersion Research Environment (SIRE)
- Virtual Environment Interface Laboratory (VEIL)
- Fusion Interface for Tactical Environments (FITE)
- Alternative Control Technology (ACT)

Advanced Helmet Display Systems
- Night Vision Operations Laboratory
- Visually Coupled Systems Development and Visual Interface Laboratory
- Visual Image Evaluation of Windscreens Laboratory
- Dynamic Visual Assessment Facility (DVAF)
- Color Display Laboratory (CDL)
- Aerospace Vision Laboratory (AVL)

TABLE 1-1: LIST OF HUMAN ENGINEERING DIVISION FACILITIES

The core program, accounting for approximately 70 percent of the activity of the Fitts Human Engineering Division, is focused on building the technology base, tools, techniques, and media to leverage and extend the capabilities of future warfighters in the operation and support of complex systems. Analogous to "fire-prevention," these efforts are concerned with preventing today's problems from recurring in tomorrow's systems by anticipating USAF needs and getting "ahead of requirements." In performing this activity, user needs must often be "pushed" to recognition of emerging human engineering technologies and best practices (Figure 1-3). Our considerable success in this area is demonstrated by a sustained high percentage of customer funding of our science and technology program.

Work is executed through five Branches: Ergonomics Analysis; Design Technology; Human Interface Technology; Crew Systems Integration; and Visual Display Systems. Within the division, there are 18 specialized laboratories and facilities (Table 1-1) distributed over six buildings (Bldgs 248, 248A 33, 196, 197, 29) on Area B of Wright-Patterson AFB. The core strength of the organization is reflected in the quality and breadth of division personnel (Figure 1-4). Our present staff includes 86 civil service, military, and visiting scientists, over 60 percent of whom hold advanced degrees (26 percent MS, 35 percent PhD, two percent

FIGURE 1-4: HUMAN ENGINEERING DIVISION STAFF (AS OF DEC 94)

Top to Bottom and Left to Right (10 Rows)
1. Anne Cato, Albert Chapin, Alan Pinkus, Capt Scott Smith, 1st Lt Bryan Christensen, Alan Straub, William Kama, Robert Osgood, Bradley Purvis
2. Dean Kocian, Christopher Russell, Craig Arndt, Donald Monk, David Post, Herschel Self, Gregory Zehner, John Bridenbaugh
3. Jeffrey Craig, Gloria Calhoun, Gilbert Kuperman, Grant McMillan, Gary Reid, Glenn Wilson, Capt Jeffrey Hoffmeister, Denise Wilson, Brian Tsou
4. Capt John Crist, Capt Stuart Turner, Lt Col James LaSalvia, Joe McDaniel, June Skelly, Jennifer Whitestone, Kathleen Robinette, Reuben Hann
5. Lee Task, Capt Larry Wiley, Maj Julie Cohen, Beverly Gable, Mark Cannon, Marya Beverly, 1st Lt Mike Kasic, Capt Luis Rodriguez, Laura Mulford
6. Earl Sharp, 1st Lt Michael Stratton, Lt Col Michael Eller, 1st Lt Lawrie Hamacher, Michael Haas, Mary-Louise Smith, Sqn Ldr Greg Underhill, Michael Vidulich
7. Lt Col Melvin O'Neal, Lt Col Paul Morton, Randall Brown, Renee Kaffenbarger, 1st Lt Ralph Korthauer, TSgt Raymond Morandi, Maj Edward Fix, Capt Michael Pietryga, Peter Marasco
8. Robert Eggleston, Lt Col Gerald Gleason, Nilss Aume, Nick Longinow, SSgt Otis Newsome, Philip Kulwicki, Michael McNeese, Maj Mark Waltensperger
9. 2d Lt Darryn Bryant, Maris Vikmanis, Melvin Warrick, Walter Summers, 1st Lt Robert MacMillan, Capt Ronald Merryman, MSgt Robert Stewart, Richard Warren, Capt Steve Beyer
10. Robert Centers, Rebecca Green, Theresa Schiavone, Elizabeth Combs, Lt Col William Wittman, Helen Redwine-Smith, Tanya Ellifritt, Ronald Yates, TSgt Wiley Wells, Kenneth Boff


Fitts Human Engineering Division
(Staff as of December 1994)

FIGURE 1-4

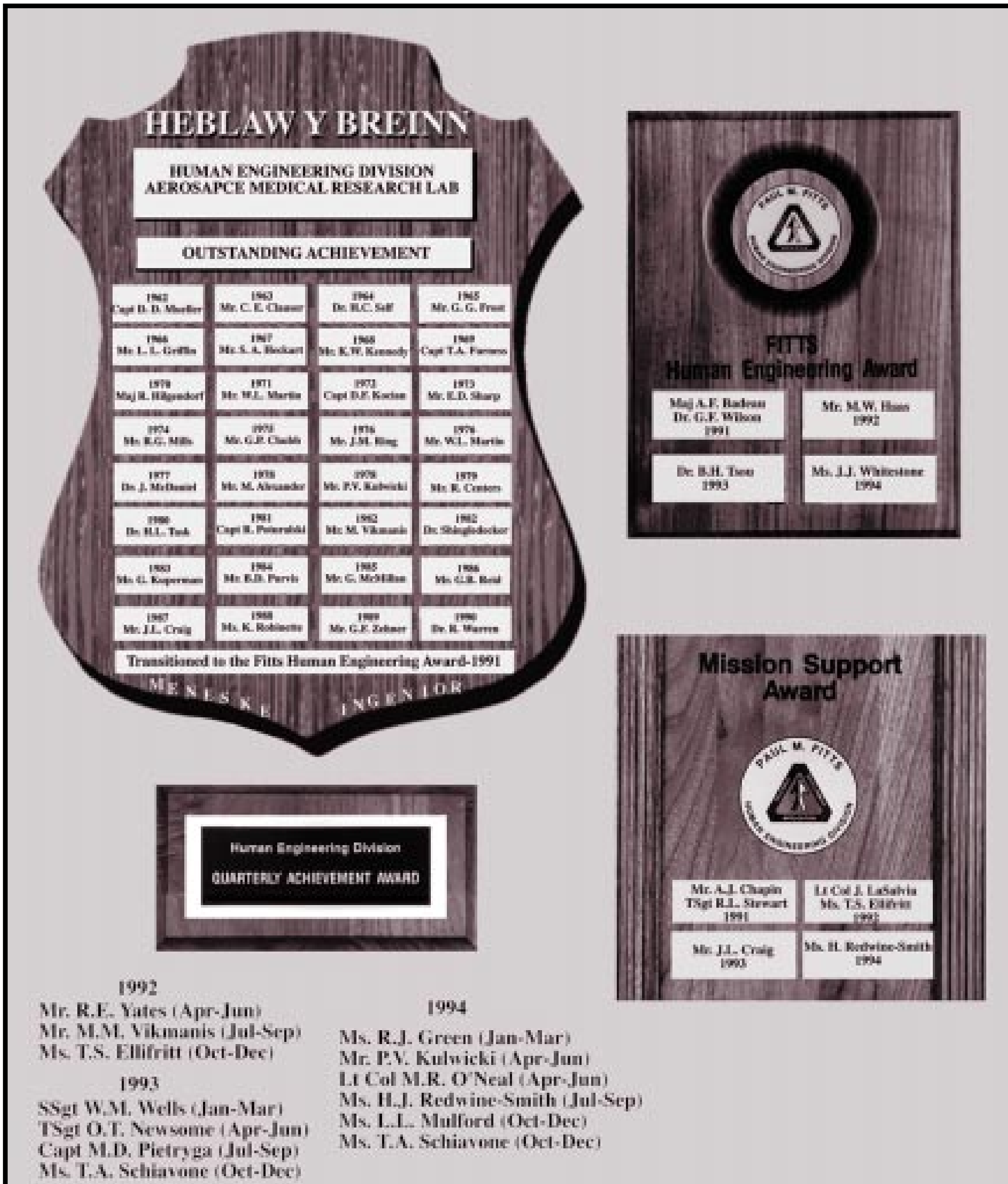

FIGURE 1-5: HUMAN ENGINEERING DIVISION AWARD WINNERS

MD) representing a wide range of scientific and engineering disciplines including psychologists, physiologists, physicists, physicians, mathematicians, computer scientists, and aeronautical, electrical, human factors, industrial, and mechanical engineers. These division researchers are generally recognized nationally and internationally in their respective areas of expertise and have collectively authored numerous scientific publications as journal articles, technical reports, books, and symposia proceedings.

Several awards are conferred to honor the achievements of division personnel. The winners of these awards are noted in Figure 1-5. The Paul M. Fitts Award for Human Engineering Excellence is awarded for significant achievement in human factors basic science, engineering, or technology transition. It has been awarded annually since 1991, at which time it replaced the division's Human Engineer of the Year Award, first awarded in 1962. The Mission Support Award was also initiated in 1991, and is awarded annually to members of the staff who, in the spirit of total quality management, exceeded their job requirements; displayed initiative, perseverance, and dedication of mission; improved management procedures or methods of service; proved successful in administration, contract management, or coordination of programs; or successfully represented the division with outside organizations. Additionally, a division Quarterly Achievement Award is given to individuals whose accomplishments over the preceding three months have significantly furthered the Human Engineering Division or brought recognition to the division in the science and engineering communities.

Supplementing this government staff is a multi-disciplinary cadre of approximately 170 on-site support professionals representing six independent R&D companies. These are Ball Systems Engineering Division, Logicon Technical Services Inc. (LTSI), Science Applications International Corporation (SAIC), Sytronics, Inc., University of Dayton Research Institute (UDRI), and VEDA Inc. Whereas the division takes pride in its core competency and technology leadership, as demonstrated by the quality of its in-house research programs, these and other contracts with universities and industry extend our capabilities and encourage external participation.

The unique R&D assets within the Fitts Human Engineering Division make it a national center of excellence which leads the nation's human factors research efforts. Our value continues to grow with public recognition that effective human integration with complex technologies in tasks, jobs, and processes from the factory floor to the family living room is the key to affordability and international economic competitiveness. Products from our R&D investments have been extensively and successfully used by industry, academia, local government, and other federal agencies. Multi-use applications have been achieved, or are planned, in medical instrumentation and techniques, automotive interior packaging and assembly, industrial safety and job design, job performance aiding, computer-aided human engineering, and entertainment.

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SECTION 1 - 50 YEARS OF HUMAN ENGINEERING: NARRATIVE HISTORY

II. HISTORY

The remainder of this section is divided into two parts: Human Engineering: 1945-1984, and Fitts Human Engineering Division: 1985-Present. This somewhat unusual structure was selected, in part, to reuse a remarkable history of the division's first 40 years, written by Dr. Walt Grether for the occasion of the 50th anniversary of the Air Force Aerospace Medical Research Laboratory. In it, he captures the flow of important events, the goals, and the mood of the organization throughout the 40-year period. Following Dr. Grether's account is a contemporary perspective of the Human Engineering Division focusing on the most recent ten years of its existence. This thorough overview of the division's structure, mission, practices, research programs, accomplishments, and facilities provides a snapshot of the division and its members today and is a sound basis for predicting the future of the organization over the next 50 years.

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HUMAN ENGINEERING: THE FIRST 40 YEARS* 1945-1984

by Walter F. Grether, PhD
Chief, Psychology Branch (1949-1956)

Today we are celebrating the 50th anniversary of the founding of the great institution that is now called the Air Force Aerospace Medical Research Laboratory. During the 50 years of its existence, this laboratory has contributed immensely to the development of Military and Civil aviation, and manned space flight, in terms of the safety and effectiveness of human beings. In this paper I will discuss early activities relating to another anniversary, the 40th anniversary of what is now called the Human Engineering Division of the Aerospace Medical Research Laboratory. On 29 May 1945, HQ Army Air Forces directed the Air Material Command at Wright Field to establish a psychological research facility to study equipment design problems. As a result, there was established, on 1 July 1945, a Psychology Branch of the Aero Medical Laboratory. For convenience, in this paper I will refer to the laboratory by its common abbreviation, AMRL.

My first knowledge about the plans for this new Psychology Branch came just about this time 40 years ago. I was serving as Chief of a Psychological Examining Unit at Keesler Field, Biloxi, MS. This Psychological Examining Unit was part of a large World War II Aviation Psychology Program, under the Office of the Air Surgeon, devoted primarily to the selection and classification of Aircrew Personnel. This news came to me from Dr. Paul M. Fitts (Lt Col), stationed in the Office of the Air Surgeon. He had been selected to head the new venture at Wright Field and invited me to join. The proposed program, pioneering a new field, interested me very much, and I promptly volunteered for assignment to the new Psychology Branch of AMRL.

Most of the initial staffing of the Psychology Branch was by officers and enlisted men from the wartime Aviation Psychology Program, which, during most of the war, was centered in the AAF Training Command. At this time, 40 years ago, the war in Europe had ended, and the war in the Pacific was in its final stages. Thus, the program we were in would obviously be scaled down.

I was one of the first of the staff of the new branch to arrive at AMRL in August 1945. Dr. Fitts arrived a few days later. Soon many others, mostly military, and a few civilian, joined the new branch. We were graciously welcomed by the Laboratory Commander, Dr. William R. Lovelace, III (Colonel). Others in the laboratory also seemed pleased to see us, and made us feel very welcome. At that time most of AMRL was housed in building 29, and four adjoining one-story buildings which are still in place. An animal facility and some hydroponic gardens north of building 29 were removed long ago. Initially space was made available for us in building 29. Rather soon, as a new building was completed for the Engineering and Development Branch, we were able to expand into buildings 196 and 197. Within a few years, we learned of another new building, number 248, to be built for the Physiology Branch, thanks to Dr. Pharo Gagge, who was chief of Operations at that

* Originally written as “The Genesis of Human Engineering” for the occasion of the 50th anniversary of the Air Force Aerospace Medical Research Laboratory. Portions were published in “50 Years of Research on Man in Flight," 1985, Charles A. Dempsey.

time. Two additional floors were added to the plans for building 248, specifically for the Psychology Branch. Building 248 is still the home of the present Human Engineering Division.

With the war drawing to a close, why did the Air Force find it necessary to set up a new and pioneering program of psychological research? For the answer to this question, we have to look at some of the lessons learned from wartime combat operations. One of these lessons, as Dr. Stevens of Harvard University stated, was that “Machines Cannot Fight Alone.” A major weakness in many weapon and support systems was the human operator. Far too many aircraft and their crews were lost because of pilot or navigator error. Bombing accuracy fell far short of what the systems should have been capable of delivering. Fire control by fighter aircraft, and flexible gunners, also was disappointing. Although the human operator proved to be a major weakness, it was realized that much of the fault was in the original design of the equipment, which was often poorly matched to the physical and intellectual capabilities of the men and women who had to use it. To overcome this problem much effort had gone into selecting and training the operators, but this was not enough. Research was needed to find designs which were more compatible with human capabilities.

During the war a few of these design problems had been investigated by psychologists. At the Harvard Psychoacoustic Laboratory, for example, research led to significant improvements in the design of radio communication systems. At a number of other places, psychological research efforts were applied to fire control and radar systems. In Great Britain, also, there were some wartime research efforts by psychologists on equipment design problems. The major effort was at Cambridge University, under Sir Frederick Bartlett.

It was not until after the war, however, that a major attack was made on the problems of designing equipment for human operation. At about the same time that the Air Force set up the Psychology Branch, the U.S. Navy set up several new research units with similar missions. These were at the Special Devices Center on Long Island, the Navy Electronics Laboratory at San Diego, and the Naval Research Laboratory at Anacostia, MD. In addition, the Navy initiated a major contract program with Johns Hopkins University to study Combat Information Centers. At this time, also, the Psychological Corporation in New York set up a new group to do contract work on equipment design problems. This group soon split off to become Dunlap and Associates. It was not until about 6 years later that the US Army established a Human Engineering Laboratory at Aberdeen Proving Grounds in Maryland.

At AMRL we first used the label “Engineering Psychology” for our type of activity. Our counterparts in other laboratories, however, began using other labels such as “Human Engineering,” “Human Factors,” “Human Factors Engineering,” and “Biomechanics.” Our counterparts in Great Britain used the term “Ergonomics.” While all these labels are still in use, in this paper I will use the term “Human Engineering.”

For those of us in the new Psychology Branch, coming to AMRL and Wright Field was a very stimulating experience. In the Training Command we were accustomed to marching cadets and training aircraft. We were also quite familiar with the then-current operational aircraft. At AMRL and Wright Field we began learning about the Air Force of the future. At AMRL we learned about partial pressure suits, advanced G suits, atomic flash protectors, and liquid oxygen converters. Being located at Wright Field, we also learned about jet aircraft, rocket engines, transistors, new concepts of air traffic control, new ideas for aircraft cockpits, and many other new areas of aviation development.

We also had much to learn about how to do things the Wright Field way. Here we suddenly became engineers, project engineers, that is. The fact that we were psychologists, and not engineers, did not seem to matter. Research work was organized into projects and tasks. Once a project was established, it went on forever, it seemed. We had to keep data in

Project Record Books, which were periodically inspected to be sure that we did it right. We also learned that most scientists in the laboratory, I mean project engineers, did not really do research. They developed and tested end items, such as new oxygen masks, G suits, partial pressure suits, and sunglasses. The Project Record system at Wright Field was geared to the development of end items, not to research. We had come to do research, and the end items to which our research would have application were the responsibility of other Wright Field laboratories, not AMRL.

Also strange to us was the reporting system we were required to use for publication of our research results. The required type of report was called a Memorandum Report, and was geared strictly to the development and evaluation of end items. It was quite inappropriate in format for the reporting of scientific experiments. Fortunately this situation was only temporary. In a few years a new type of reporting system was introduced, with the use of Technical Reports for major studies, and Technical Notes for studies of lesser scope. These reports were far more suitable for reporting scientific experiments.

Another thing we soon discovered after our arrival at AMRL was money, in this case contract money for the purchase of research equipment and research. In the process of getting our program underway we had to set up new projects and thereby get into the budget cycle for funding in future years. It turned out that other projects in the laboratory had funds surplus to their needs, and we were literally deluged with funds that were transferred to us. Thus, we soon found ourselves hustling to write work statements for research equipment that we needed, and for research that we could farm out to university contractors. We were most fortunate to have this windfall of contract money to help us launch our new program. Amazingly, we were even provided with transfer of funds from other Wright Field laboratories that were anxious to have us supervise research related to their areas of responsibility.

As I mentioned earlier, the initial staffing of the Psychology Branch was mostly officers and airmen from the wartime Aviation Psychology Program. As the war ended, most of these people separated from the Air Force and returned to universities or other civilian occupations. Some of us, including Julien Christensen and Melvin Warrick, converted to Civil Service status and stayed at AMRL. Those who left were soon replaced with other officers and enlisted men, and some civilians. Among the new additions were pilots, navigators, and bombardiers, some of them with no training in psychology. They were, however, most valuable additions to our group because of their personal knowledge of flight operations and flight crew duties. I have a picture of the Psychology Branch staff, taken in 1948 (Figure 1-6). Dr. Fitts, our most inspiring and capable leader, is seated in the center front row. We were all very sad when he left us in 1949 for a position at Ohio State University, although he continued to assist us in many ways after that. We were saddened even more when he passed away suddenly at Ann Arbor, Michigan in 1965.

At the time this picture was taken, a few members were absent and failed to get into the picture. About 10 years after this picture was taken, the Anthropology Section, under Ed Hertzberg, joined our branch. Some years later, also, our mission was expanded, and new personnel added, to include research on training, with special emphasis on design of training devices and equipment. Dr. Gordon Eckstrand headed up this new activity.

Early in our existence, to give proper direction to our research, we began visiting the nearby laboratories whose end items would be the focus of our research. These laboratories were primarily Communication and Navigation (radios, instrument landing systems, and air traffic control), Equipment (aircraft instruments, instrument and cockpit lighting), Aircraft (crew station design and layout), and Armament (radar and fire control systems). After the project engineers in these laboratories understood that we were not there to develop end items in their areas of responsibility (I think this is called turf these days), they were happy to tell us about operator problems they had encountered.

FIGURE 1-6: THE PERSONNEL OF THE AMRL PSYCHOLOGY BRANCH IN 1948
From the left, back row: Lt Wise, Mr. Bakalus, Mr. Gardener, Miss Fuerst, Mr. Roettele, Miss Connell, Mr. Warrick, Mrs. Morris, Mr. Christensen, MSgt Kake, Sgt Edison, and Mr. White Seated in the front row, from left: Capt Jones, Maj Long, Dr. Fitts, Dr. Grether, Dr. Biel, and Capt Wilcox.

They were very receptive to the idea of having us conduct human engineering research applicable to their equipment. From our discussions of these problems with them, we gained many valuable research ideas. For some of the problems they described, we could provide data from the available psychological research literature. They brought up other problems, however, which we saw no way of solving through research we could visualize. We also received some wild proposals, and these we politely rejected. One such proposal came to us in a letter requesting us to supervise a research program on Extra Sensory Perception, as a possible substitute for radio communication. I was quite familiar with research literature in this field, and sent them a diplomatic reply explaining why such research would not be productive.

In this paper, I will briefly describe some of our very early research efforts, and the successes or failures of these in terms of applications to Air Force equipment. Some of these studies were originally reported in Volume 19, of the AAF Aviation Psychology Program Research Reports (4) which the branch had ready for publication in October 1946.

For his effort to educate himself about problems needing research attention, particular credit must go to Julien Christensen, a former AF navigator. Dr. Christensen (2) arranged to conduct activity analyses of navigators in B-29 aircraft during very long operational-type missions, mostly in the Arctic. This gave him valuable data on how the navigators carried out their duties in our newest operational bomber, how their work time was distributed, and what problems they faced. It also gave Chris membership in the Pole Vaulter's Club, and the right to the claim as the first civilian to fly over the North Pole in an Air Force aircraft. Christensen also conducted research on errors made by navigators in using their standard navigation plotter. His experimental evaluation (3) of several different plotter designs led him to design an improved plotter which became the standard for use in the Air Force. This was the first, and one of the few end items ever developed by the Psychology Branch.

A major problem that had plagued the Air Force during the war, and before, was pilot error as a major cause of aircraft accidents. Statistical data maintained by the Directorate of Flight Safety Research, at Norton AFB, San Bernardino CA, consistently showed that about 75% of major aircraft accidents were attributable to pilot error. It can be argued that many of these were really designers' errors, that trapped the pilots into making what were often fatal mistakes. A very common type of error was activation of the wrong control. At that time each type of aircraft had a different arrangement of controls and instruments in the cockpit. Thus, when a pilot changed from one type of aircraft to another he was very like to reach for the wrong control, or read the wrong instrument. Also, some controls were located in places where they were difficult to reach or to see. This particular source of pilot error was largely eliminated in future aircraft by two major changes in cockpit design: (1) standardized location of major controls and instruments in the cockpit, and (2) shape coding of major cockpit controls. Thus, when a pilot transferred to a different type of aircraft he did not have to relearn the location of major cockpit items, and major controls could be identified by touch alone. These changes were implemented primarily by the Crew Stations Branch of the Aircraft Laboratory, with much technical input from members of the Psychology Branch, using the results of several experiments. One of these experiments, by William Jenkins (10), tested the identifiability by touch alone, among a group of shape-coded control knobs. Figure 1-7 shows the knobs that were included in this experiment. Pilot Dick Jones is shown as the subject. Another experiment, by Fitts and Crannell (5), measured the accuracy with which pilots could reach to possible control locations in the cockpit. An experiment by Mel Warrick (13) determined the preferred relationships between control movements and instrument indications when these were located in different axes or planes in the cockpit. The Anthropology Section (which later transferred to the Psychology Branch) provided very essential data about cockpit sizing to accommodate the full range of pilots' body dimensions.

An important aspect of the cockpit standardization effort was agreement on a standardized arrangement of the six flight instruments, namely the horizon, altitude, air speed, rate of climb, heading, and rate of turn instruments. A major contribution toward agreement on the best arrangement of these instruments came from a pilot eye movement study conducted by Fitts, Jones and Milton (7) in a C-45 aircraft assigned to the branch. This study measured the frequency and pattern of eye movements during different phases of flight.

As already mentioned, pilot error had been a major cause of aircraft accidents. In most cases the pilots could not be interrogated to determine the exact nature of the error, and this could only be deduced from the accident data. One of the first studies conducted in our branch was an interview study by Fitts and Jones (6) in which pilots were asked to recall and describe errors they had made in flight that could have resulted in accidents. Among these were errors in reading instruments. A sample of some of the findings regarding

FIGURE 1-7: CODING AIRCRAFT CONTROL KNOBS
Knobs employed in a study of shapes for use in coding aircraft control knobs. (Capt Richard E. Jones as subject). From Jenkins (10).

instrument reading errors is shown in Table 1-2. You will note that the category with the highest frequency of errors was in reading multirevolution instruments. Mostly these were errors in reading the standard three-pointer altimeter used in most military and civilian aircraft at the time. This finding led me to conduct an experimental study of altimeter reading (8), using nine different types of altitude display that might be suitable for use in aircraft. Both college students and pilots were used as subjects. The results show that this instrument takes a rather long time for reading, and yields a high percentage of reading errors. Unfortunately, many of the reading errors were in the hazardous direction of reading the altitude as higher than it actually was. The most common mistake was to read the altitude as exactly 1,000 feet too high. We believe this type of reading error accounts for a great many unexplained accidents in the past, where aircraft hit mountains just below the peak, or landed just short of the runway on instrument approaches to landing.

Based upon the results of this experiment, I recommended that the altimeter be redesigned to provide a display which uses a single pointer making one revolution for each 1,000 feet change of altitude. An added odometer type of indicator displays thousands and ten-thousands of feet altitude. Both pilots and college students made almost no errors with this display, and reading time was very short. In ensuing years several investigators in other laboratories conducted experiments with similar displays and corroborated these results. Unfortunately, the engineers responsible for altimeter design were unwilling to give up the mechanically reliable three-pointer design. It was not until about 20 years later that the altimeter was changed to provide the greatly improved type of display. The change was then made because a redesigned instrument was needed so that altitude could be automatically transmitted by radio link to the ground, for air traffic control purposes. The improved type of altitude display is now standard in most military and commercial aircraft.

These are a few of what you might call successful outcomes of our early research. Some of our other studies might be of equal interest, even though they did not produce the hoped-for results. As we know, negative results, or results that do not lead to practical applications, can also be of great value.

Late in the war the B-29 was a very important aircraft in our inventory, and it played a key role in ending the war in the Pacific. In this aircraft, at the waist gunner station, was a very advanced type of gun sight known as the pedestal sight. Gunners had considerable difficulty in using this sight, and accuracy was considerably below expectations. We were requested by the Armament

TABLE 1-2

Classification of 270 Errors Made by Aircraft Pilots
in Reading Instruments
(Modified from Fitts and Jones, 1947)

Type Error	Percent
Misinterpreting Multi-Revolution Instruments	18%
Misinterpreting Direction of Indicator Movement (Reversal Errors)	17%
Misinterpreting Visual and Auditory Signals	14%
Errors Involving Poor Legibility	14%
Failing to Identify a Display	13%
Using an Inoperative Instrument	9%
Misinterpreting Scale Values	6%
Errors Associated with Illusions	5%
Omitting the Reading of an Instrument	4%

Laboratory to evaluate two sets of redesigned controls for this sight. The original controls, because of their design, caused interference for the operator between the separate tasks of controlling elevation, azimuth, range, and triggering. Also, an undue part of the load was given to the left hand. It was rumored that the designer of the sight was left-handed. An experiment, conducted by Johnson and Milton (11), showed one of the redesigned sets of controls to be clearly superior to the original controls. In this instance, however, no effort was made to install the improved controls in B-29 aircraft, since further combat use of this aircraft seemed unlikely.

As mentioned earlier, our branch had a C-45 aircraft assigned to it, and this was used very successfully for experimentally recording eye movements in flight. This success led us to request a larger aircraft, a C-47, for research on other aspects of pilot performance, with special emphasis on pilot fatigue. A question that we encountered quite often was "How long can a pilot fly safe under instrument conditions?" Past research on fatigue, by others, had generally been disappointing. Although pilot fatigue seems to be a genuine problem, and a serious flight hazard, this condition had been extremely resistant to objective measurement. We had the C-47 aircraft equipped with a remote panel of instruments, for photographic recording of pilot performance. Missions were flown with the pilot under an instrument flying hood. The missions were 14 hours in length, with a refueling stop at midpoint. Detailed analysis of the instrument recordings failed to show a significant decrement during the 14 hour missions. There were, however, subjective indications that the pilots were quite fatigued. One of the pilots, in his hurry to get home and rest, hit another car as he backed out of his parking space.

Another research area to which we gave considerable attention, and some research, was the issue of "Fly To" and "Fly From" on aircraft instruments. Another way of stating the question was, should the moving element of the instrument represent the aircraft (a "Fly From" indication), or should it represent the earth (a "Fly to" indication)? On most instruments the moving element represents the earth. This conflict could be expected to cause habit interference on the part of pilots. Our pilot interview studies referred to earlier showed that pilots frequently made reversal errors in flying the gyro horizon and radio compass. A wartime study by Loucks (12) at the AF School of Aviation Medicine had shown that it was more natural to fly the moving bar of the gyro horizon as if it were the aircraft, rather than the horizon. Similar results were obtained by Brown (1) in Great Britain. Early in our program we acquired a wartime Link Trainer, and two of our employees, Joe Bakalus and Bob Roetelle, were former Link Trainer operators. With their help, John Gardner, one of our pilots, did a study of methods of horizon display. His results agreed with those of previous studies. A change to the moving aircraft type of display was, however, never seriously considered by the engineers responsible for the design of flight instruments. In retrospect, I think they were probably right. For a rather long time now the standard gyro horizon display has been a stabilized sphere, which can display all possible aircraft attitudes. The moving aircraft type of display, as far as I know, is not amenable to such all-attitude representation.

There was another long-standing idea that engaged some of our early thinking. Actually this was not so much our idea, as that of anthropologists and biophysicists in AMRL. This was the idea that the pilot, in a fighter aircraft, might fly in the prone position, as the Wright brothers did in their first aircraft. This position would give the pilot considerably increased G tolerance, and would also permit a reduced vertical cross section of the aircraft. The Psychology Branch provided some help in testing this idea. Through a contract with the University of California at Berkeley, we had a set of controls constructed for flying in the prone position. Under the auspices of the Anthropology Section a prone position bed, and the controls, were installed in the nose of a B-17 aircraft as a test vehicle. Quite a few of us had a chance to actually fly the B-17 using this novel arrangement. I think even the anthropologists agreed that this position had some serious disadvantages, among them being the difficulty of forward and upward vision. The idea seems to have been laid to rest as a result of this trial.

In this report I have given you a flashback to some of the pioneering research of the Psychology Branch during the first five years of its existence, and I showed how some of these research studies contributed to aviation development. In the ensuing years, the Psychology Branch, later renamed the Human Engineering Division, continued as a leading organization for Human Engineering research. Beginning in the late 1950s, as manned space flight became a possibility, much research of the branch was directed to problems of working under zero-gravity conditions, cycling of work and rest during prolonged confinement, and other problems related to manned flight in space. During some of the same period, as our nation was engaged in the Vietnam War, other research efforts were directed to Limited War types of aviation operations. Major contributions were made in both of these rather different areas. From the modest beginning made by the Psychology Branch, and several parallel research organizations in the US Navy about 40 years ago, Human Engineering has grown into a large and widespread area of applied science. There are now probably several thousand persons employed as Human Engineers in this country, in the Department of Defense, in defense and nondefense industries, consulting firms, and universities. Some of this expansion of Human Engineering was covered in a review I prepared in 1966 (9).

In conclusion I would like to express my personal satisfaction with the 28 years I spent at AMRL. Approximately seven of those years were as Chief of the Psychology Branch, following Dr. Fitts. The remaining years were in various staff positions. I enjoyed my association with the medical and medically related specialists who made up the laboratory. I also enjoyed my close association with development engineers in other Wright Field laboratories.

After 40 years the Human Engineering Division is still a vigorous and productive organization. This is due in large part to the leadership provided by Dr. Julien Christensen, who followed me as Chief, and Charles Bates, the present Chief. It is also testimony to the past history of accomplishments of this organization, and to the administrative support and scientific environment provided by AMRL.

REFERENCES

1. **Brown, R. C.**, (1945). *Comparative trial of two attitude indicators.* Brit. Flying Pers. Res. Comm. Rept. 611a.

2. **Christensen, J. M.**, (1947). Psychological factors involved in the design of air navigation plotters. Chapter 5 in P. M. Fitts (Ed.) *Psychological research on equipment design. Washington D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

3. **Christensen, J. M.**, (1949). A method for the analysis of complex activities and its application to the job of the Arctic aerial navigator. *Mechanical Engineering, 71*

4. **Fitts P. M.** (Ed.), (1947). Psychological research on equipment design. *Washington, D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

5. **Fitts, P. M., and C. Crannell**, (1950). *Location discrimination. II. Accuracy of reaching movements to twenty-four different areas.* USAF Air Material Command Technical Report 5833.

6. **Fitts, P. M., and R. E. Jones**, (1947). *Psychological aspects of instrument display. I. Analysis of 270 "pilot-error" experiences in reading and interpreting instruments.* USAF Air Materiel Command Mem. Report TSEAA-694-12A.

7. **Fitts, P. M., R. E. Jones, and J. L. Milton**, (1950). Eye movements of aircraft pilots during instrument landing approaches. *Aerospace Engineering Review 9.*

8. **Grether, W. F.,** (1949). Instrument Reading. I. The design of long-scale indicators for speed and accuracy of quantitative readings. *J. Appl. Psychol. 33(4).*

9. **Grether, W. F.**, (1968). Engineering Psychology in the United States. *American Psychol. 23(10).*

10. **Jenkins, W. O.,** (1947). Tactical discrimination of shapes for coding aircraft-type controls. In P. M. Fitts (Ed.), *Psychological research on equipment design. Washington, D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

11. **Johnson, A. P. and J. L. Milton,** (1947). An experimental comparison of the accuracy of sighting and triggering with three types of gun-sight handgrip controls. In P. M. Fitts (Ed.), *Psychological research on equipment design. Washington, D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

12. **Loucks, R. B.,** (1947). An experimental evaluation of the interpretability of various types of aircraft attitude indicators. In P. M. Fitts (Ed.), *Psychological research on equipment design. Washington, D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

13. **Warrick, M. J.,** (1947). Direction of movement in the use of control knobs to position visual indicators. Chapter 9 in P. M. Fitts (Ed.), *Psychological research on equipment design. Washington, D.C.: US Government Printing Office, (Vol. 19, AF Aviation Psychology Program).*

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FITTS HUMAN ENGINEERING DIVISION: 1985-PRESENT

A. INTRODUCTION

During the last ten years, the Human Engineering Division of the Armstrong Laboratory has been very productive in many areas. In appraising just how productive the division has been during these years, it is important to keep in mind that the division is a research and development (R&D) organization with two products or outputs: its publications and its direct assistance to organizations that develop, evaluate, and use man-machine systems. The division conducts both laboratory and field studies to collect data on the physical and mental abilities of people for use in designing, developing, and applying man-machine systems. These data allow tailoring of equipment to fit its users so that man-machine systems fully utilize the abilities of both the equipment and its users.

A cursory examination of the entries in the bibliography over the last ten-year period reveals that, during this period, the Human Engineering Division was a prolific publisher of journal articles and technical reports. However, it should be noted that the bibliography does not fully reveal the extent of direct assistance and development work by the division, since an appreciable part of the development work had security classifications that prevent inclusion in this volume. The authors of this document readily admit that not all research and development conducted in the Human Engineering Division is represented in this work. Because of classification, sensitivity, expediency, or oversight, the work of many talented researchers was unfairly underrepresented or omitted altogether. In those cases, we beg your indulgence. We felt that complete representation was not practical and, in fact, not desirable. Our goal was the inclusion of a broad, representative set of topics illustrating the major activities of the organization and the time. Again, our apologies to those whose work has been slighted.

During the last ten years, much of the research and development work of the Human Engineering Division on specific topics and problems was continued from previous years, because many of the problems required still better solutions. In some cases, changes made in systems under investigation required new human engineering inputs for evaluation. In some cases, new problems surfaced during use of new systems. In the relatively short span of the last ten years, the advance of technology has caused significant changes in both the equipment used by the armed forces and in laboratory equipment. The constant pressure to increase operational effectiveness and maintainability while decreasing lifetime cost of ownership of aircraft and space vehicles was accompanied by changes in their displays, controls, operating procedures, and combat tactics. Changes were usually in the direction of increased complexity and were not always effective.

Increased use of computers is one factor influencing division work. Although digital computers have been around for several years, in the last ten years there has been an appreciable increase in the number of computers and output media in offices, laboratories, and military systems. There has also been a large increase in the percentage of laboratory and operational equipment having digital indicators and displays, with digital devices in many cases replacing analog devices. Instruments for measuring many quantities, such as the amount of fuel in a tank, aircraft speed, weight, dimensions of parts of the human body, strength, etc., are now automatically converted at the measuring device to digital form for display and for storage in computer memory. Increasingly, the process of collecting data bypasses the need to read numerical values and manually record them by writing or keyboard use. Once in the computer, statistical data analysis programs allow computers to perform any desired statistical calculations, provide tables of numerical values, and draw graphs, charts, and complex illustrations. The technical reports on the results of research and development efforts are now written with the aid of word processors, frequently by the engineers and scientists using their own computers.

To illustrate the effect of the digital revolution on the work of the Human Engineering Division, in 1988 the division's physical anthropologists acquired a computer-controlled laser scanner that automatically measured the three-dimensional (3-D) coordinates of human heads and recorded the data in computer memory. The computer data have been used to automatically control a milling machine that turns a block of material into a replica of the scanned head. Within a brief time after a subject is scanned, a 3-D solid replica of the head is available. Formerly, several days to weeks were required. The scanner greatly increases the ability of the division to collect survey data for designing or evaluating helmets and head-carried equipment, such as oxygen masks and night vision goggles.

There is still plenty of work to be done; as technology advances, new problems will occur and old ones will require better solutions. Hence, human engineering must also advance. The Human Engineering Division has an important role in this advancement, and is looking forward to the next 50 years of human engineering.

B. SCIENCE & TECHNOLOGY PROGRAMS

1. Human-System Performance Research

Performance and Workload Assessment

This research and development activity was directed toward generating subjective, behavioral, and physiological metrics and measurement methods for evaluating operator workload, situation awareness, and decision making in Air Force systems. This research has had two principal foci: workload and situation awareness measurement. These two areas can be thought of as representing attempts to quantify the demands placed on a system operator compared to his/her ability to accommodate the demand in performing the mission (workload) and quantifying or characterizing the quality of the information processing while the operator is performing his/her mission (situation awareness). The tools developed during this period have played an important role in comparing alternative interface designs and establishing the viability of a specific design for achieving mission requirements.

In June of 1979, the Workload and Ergonomics Branch was formed to address a growing concern of Air Force operators and planners about the information processing demands being placed on systems operators of emerging high-technology systems. The Branch Chief, Maj Robert O'Donnell, assembled a team of government scientists, contractors, and academic researchers to pursue a three-pronged research program to develop metrics of human mental workload. The act of organizing a branch around a technical problem, in and of itself, was unique. Typically, human factors organizations are organized around generic, operationally oriented factors such as controls, displays, or training.

Mental workload became a very hot research topic in universities and government laboratories around the world. Additionally, the problem of information in aircraft cockpits became so widely acknowledged that, in 1979, the Commander of Air Force Systems Command, General Alton Slay, proclaimed it as one of the Air Force's most pressing problems. He mandated that all new aircraft designs should take pilot workload into consideration.

Emerging technology increased operator workload in several ways. Expanded system capabilities, with a concomitant increase of displayed information, created unprecedented demands on operator attention and resources. Secondly, advances in automation technology led managers to believe that complex flight tasks could be performed with smaller crews, since large components of the tasks could be turned over to machines. This combination of events dramatically changed the nature of cockpit tasks. The push to reduce crew size was also taken up in the private sector by the airlines. When the Boeing 757 was being prepared for certification, there was a push to certify the aircraft for a two-man crew. Due to the critical nature of the issues involving many components of national interest, President Reagan formed a special Presidential Advisory Commission on Aircraft Crew Complement. Lt Col Robert O'Donnell was named as a staff member for the commission and played a very active role in producing the commission's report.

Generally, research in mental workload took one of three approaches: subjective measures, behavioral or performance measures, and physiological measures. Behavioral approaches, especially secondary task methodology, helped to define the construct of mental workload as multi-dimensional and, in some way, related to the allocation of mental resources among tasks. Subjective approaches were believed to be the most widely used, especially in operational testing. Few could argue that some method of having people estimate how hard they were working was a necessary part of studying workload. Other measurement methods ultimately have to pass the test of corresponding with what the operator believes to be true. Finally, physiological measures have had a great deal of appeal as objective ways to reflect how hard the organism is working. Academic research at the time, especially by Dr. E. Donchin at University of Illinois, focused on evoked cortical response that could be shown to have a relationship to cognitive activity. The implications for measuring workload were unavoidable.

Research, especially in the areas of behavioral models and physiological phenomena, was widespread. However, the Workload and Ergonomics Branch was the only place where all three approaches were brought together into a unified program where they could be used to complement each other in the investigation of this complex construct.

Behavioral/Performance Measures: This work was heavily influenced by the research of Dr. Christopher Wickens, of the University of Illinois, who authored a multiple resources model of human information processing. Dr. Clark Shingledecker and Dr. Thomas Eggemeier, members of the newly formed branch, explored the use of secondary task methodology. Eggemeier's work included development of a conceptual framework for mental workload that was the theoretical basis for the entire branch research program. Dr. Shingledecker explored ways to use naturally occurring task components as if they were laboratory secondary tasks and, thus, developed a methodology known as Embedded Secondary Tasks. He also studied the use of other non-intrusive tasks, such as rhythmic tapping, as indices of primary task load.

Dr. Shingledecker led a team that developed the Criterion Task Set (CTS) and released it for general use in 1984. The CTS was a unique task battery based on a model of information processing. The idea behind the battery was to develop a series of tasks that would tap specific mental resources. The goal of the task battery was to provide a standard test battery to use in evaluation and validation of proposed workload measures. This task battery work then expanded, and Dr. Shingledecker was asked to participate in a Tri-Services Working Group, chaired by Dr. Fred Hegge of Walter Reed Army Medical Center, assigned to develop a task battery for use in screening chemical defense drugs. Drugs that were being developed to counteract potential weapons often have undesirable performance effects. The Unified Tri-Services Cognitive Performance Assessment Battery (UTC PAB) was developed and extensively tested here and under contract with the University of Oklahoma.

Work on the UTC PAB spawned international interest in development of a standardized performance battery and procedures. An AFOSR-sponsored meeting hosted by A. N. Sanders at the University of Aachen, Germany was held and an AGARD working group was formed to direct the battery development. Lt Col O'Donnell presided over the Aachen meeting where Dr. G. Santucci of CERMA, Paris, France was selected as the permanent chairperson. Dr. Glenn Wilson became the Workload and Ergonomics Branch representative and the NATO/STRES (Standardized Tests for Research on Environmental Stressors) was developed. The purpose of this battery was to provide the international research community with an agreed upon, standardized group of tasks and procedures to promote exchange of information and data on human performance limitations.

Physiological Measures: The work by Drs. Donchin and Wickens on the cortical evoked response was the starting point for the development of physiological measures. From the very beginning, the objective was to package a state-of-the-art physiological test battery that could be used in research on mental workload and in Air Force tests measuring mental workload. The battery was unique in that it included the cortical evoked response, steady state evoked response, brain-stem evoked response, several heart rate measures, electromyographic measures, respiration, and eye movement. The first battery was called the Neuropsychological Workload Test Battery (NWTB) and was unique in that it had test procedures, data collection capabilities, and data analysis capabilities combined in one device. These devices were delivered to other researchers in England, the National Drug Institute, Boeing, Northrop, and the Navy.

A major spinoff of this work was the development of a clinical evoked potential laboratory in association with the Wright-Patterson AFB Medical Center, where cortical and brain-stem evoked responses were used for audiometric and vision testing in difficult cases such as premature infants and multiple sclerosis patients. These techniques have now become standard clinical practice.
Col O'Donnell also consulted with Miami Valley Hospital where a similar facility was developed.

A significant basic research program resulted in the first DOD magnetoencephalography (MEG) laboratory. The MEG work was based on the work of Dr. Lloyd Kaufman (New York University) and others, who had made significant progress in using measurement of magnetic fields to localize origins of electrical activity associated with cognitive activity. This basic research program was used to elucidate the brain activity associated with cognitive activity and to supplement EEG approaches. The facility was developed by Lt Col Charles Hatsell, M.D. and has provided a fertile research area for cooperative research with AFIT graduate students and visiting scientists from Europe.

Dr. Glenn Wilson took over the physiology laboratory when Col O'Donnell retired and has extended the laboratory work of O'Donnell into flight. In 1981, he was the first person to actually record evoked potentials in flight. The current test battery, the Psychophysiological Assessment Test System (PATS), was built upon the work of two generations of NWTBs. PATS has refined the tests and measures that are available, increased the number of data recording channels, and greatly enhanced the user interface. Another device, the Workload Assessment Monitor (WAM), was developed in 1994 as a portable data collection and measurement device. While there are many portable recorders available, the WAM is the first device with built-in, real-time measurement capabilities.

In addition to the evoked potential work, Dr. Wilson accelerated the development of peripheral measures, such as heart rate, heart rate variability, and eye movements for in-flight workload measurement. In addition to his research flights at Wright-Patterson and surrounding bases, Dr. Wilson consulted with test teams at Air Force Operational Test and Evaluation Center (AFOTEC) and AF Flight Test Center (AFFTC) and has been instrumental in having some of these techniques used in test programs with the B-1B and C-17 aircraft.

Subjective Measures: When the Workload and Ergonomics Branch was formed, it was widely accepted that subjective measures were the primary workload evaluation techniques in use. It was soon discovered, though, that while subjective approaches were often used, they generally were designed specifically for a given test, and were often modifications of techniques designed for evaluating other phenomena, such as aircraft handling qualities. There was no systematically developed and evaluated measurement system. Using Dr. Eggemeier's Conceptual Framework for Workload, an operational definition of mental workload was developed as a multi-dimensional construct. Dr. Thomas Nygren, from The Ohio State University, helped develop a conjoint analysis mathematical approach to developing a mental workload rating scale (1981). Dr. Gary Reid led the team through an extensive program of evaluation (1982-1985) to establish the measurement qualities and procedures, and refine the Subjective Workload Assessment Technique (SWAT) (Figure 1-8). SWAT was the first thoroughly developed and validated workload measurement approach, and is still one of the most widely used workload assessment approaches. Reid has been instrumental in applying SWAT in a large number of flight and simulator environments and has consulted extensively with the Air Force Flight Test Center and the Air Force Operational Test and Evaluation Center where SWAT is the standard workload measurement technique. Additionally, SWAT has been internationally accepted. Reid consulted with both the French Air Force and the German Air Force for translations of SWAT into French and German language versions.

Another subjective measure of workload is the Subjective Workload Dominance (SWORD) technique (Figure 1-9) which capitalizes on the ability of subject matter experts to make relative judgments about differences in workload. This retrospective technique has proven highly reliable and useful for establishing causes for high workload in operational settings. SWAT and SWORD are frequently used in unison to provide a more complete evaluation of operational systems.

In 1993, Drs. Gary Reid and Mike Vidulich provided support to a Wright Laboratory Technology Demonstration Program (Quiet Knight II) flight test. The Quiet Knight

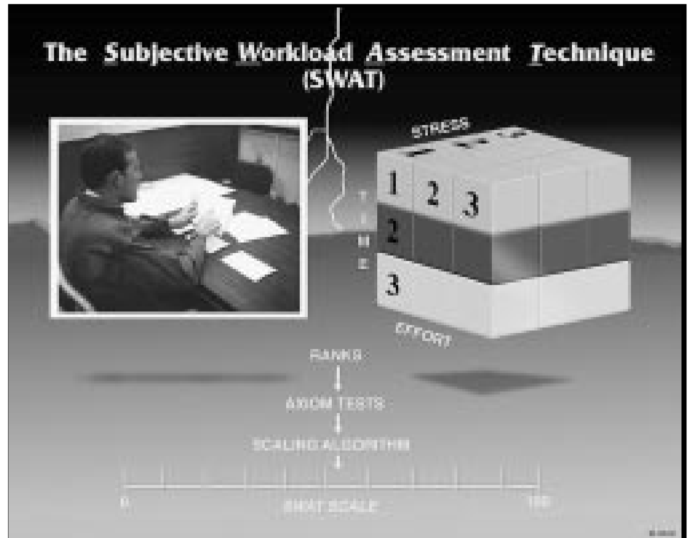


FIGURE 1-8: SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)
The SWAT was the first subjective workload metric developed at the lab. It has been widely used in the AF and throughout the world. (Project 718414)

II system was designed to make dramatic changes to the way an aircrew will perform their duties for a low-level, night-penetration mission. The purpose of the crew workload evaluation in this test program was to give an early indication of the impact of the proposed system design and task distribution on crew workload. Two subjective measurement techniques were employed: SWAT and SWORD. In general, the test demonstrated that the Quiet Knight II performs the missions

FIGURE 1-9: SUBJECTIVE WORKLOAD DOMINANCE (SWORD) TECHNIQUE
The SWORD technique is a more recent tool developed to complement SWAT in human interface evaluations. (Task 718414)

very well, and crew workload is maintained at a highly acceptable level.

Basic Visual Performance

The basic vision research program under Dr. Mark Cannon has received continuing support from the Air Force Office of Scientific Research (AFOSR) for the past 10 years. When most visual researchers were concerned primarily with measuring thresholds for detection and discrimination, this program pioneered the use of contrast scaling techniques to investigate how the appearance of targets changed with contrast. Investigations were performed for both central and peripheral vision, demonstrating that the spatial frequency pass band characteristics of the human visual system, determined from threshold experiments, did not transfer into the realm of normal everyday suprathreshold vision. These experiments were followed by development of a quantitative model of spatial pattern processing in the human visual system that could predict both the detection thresholds and suprathreshold perceived contrast of spatially localized targets presented on a uniform background. The development of this model earned Dr. Cannon a share of the US Air Force Basic Research Award in 1991. As expected, subsequent research revealed shortcomings in the model. These are being addressed by current research into the effects of background texture on the appearance of a target. Experiments have shown that background texture, similar to the target's internal structure, can produce significant changes in the perceived contrast and threshold of the target. This effect has been successfully modeled as divisive lateral inhibition and will be incorporated into the earlier visual model. The rationale behind the continuing development of this model is that its structure, consisting of parallel spatial filters and non-linear transducer functions, is something that can be easily understood by display and sensor design engineers. A fully developed model will make an ideal tool to evaluate display and sensor designs for image quality and target detection capability while it is still in the planning stage. A current reorganization of the lab will offer greater opportunities to apply the results from this basic vision research to display development programs. The research program has produced two book chapters, many articles in peer reviewed journals, many presentations at vision conferences, and several invited lectures at conferences devoted to display technology. Journal articles published under this program are highly referenced in the vision literature. The laboratory has hosted several scientists under AFOSR-sponsored programs.

Camouflage, Concealment, Deception and Obscuration (CCDO)

The Camouflage, Concealment, Deception and Obscuration (CCDO) Program, initiated by Capt Mike Tutin, Dr. Lee Task, and Mr. Bill Kama, and continued by Capt Mike Dowler and Ms. Denise Wilson, with considerable support by SRL and SAIC, developed and evaluated techniques and devices to increase aircraft and airbase survivability by reducing their detectability. The objectives were to simulate and model air-to-ground visual target acquisition of US and allied airbase assets for development, design, and evaluation of masking and camouflage patterns. Working closely with the Air Staff, AL personnel assisted in drafting an Air Force Regulation for Tactical Deception. The program led to the development and test of low-cost but highly effective aircraft decoys. The AL team also participated in a series of CONUS and OCONUS field exercises directed at quantifying the vulnerability of US and NATO airbases and the effectiveness of decoys, tonedown painting, and other vulnerability reduction techniques (Figure 1-10).

Experimental Man-in-Space (EXMIS)

In the early 1980s, the US Air Force was directed to participate with NASA in the Space Transportation System (STS) Program, otherwise known as the Space Shuttle. This meant that some shuttle launches would be designated DOD and would be partially classified to accommodate the launch of military satellites. As part of this activity, the Military Man-In-Space (MMIS) Program

FIGURE 1-10: DEVELOPMENT AND TEST OF AIRCRAFT DECOYS
Development and evaluation of low-cost aircraft decoys and other countermeasures to visual target acquisition have contributed to the Air Force Airbase Operability Program. (Task 689301)

solicited for secondary experiments to be conducted aboard these DOD shuttle missions. Dr. Lee Task and Lt Col Lou Genco proposed a series of vision studies involving both in-cabin equipment and out-cabin viewing. The vision studies proposed were an extension of the studies conducted by S. Q. Duntley during the 1960s on the Gemini program. These studies were based on some astronauts' contentions that their vision changed (some improved, some degraded) while in orbit. This led to the development of three different types of visual function testers (VFTs) conceived by Dr. Task and Lt Col Genco. VFT-1 was designed to be a self-administered, battery-operated test of visual acuity (far vision), stereopsis, eye muscle balance (vertical, horizontal, and cyclo-phoria), and eye dominance. VFT-1 flew on a total of eight shuttles, with data collected on 30 astronauts over a period of seven years. Lt Col Mel O'Neal joined the group during this period and was responsible for manifesting the device and collecting the data during the later series of VFT-1 flights. These data demonstrated that there were no overall group changes to vision due to space flight conditions for the visual functions studied, but there were some interestingly significant individual changes, especially in stereopsis, for two of the astronauts studied. VFT-2 was designed to test the visual contrast threshold (contrast sensitivity) of the astronauts' vision to determine whether or not Soviet claims to "significant degradation" of contrast sensitivity during short-term space flight could be substantiated. VFT-2 flew on six shuttle flights with the data collected on 14 astronauts demonstrating that there were no significant group changes in contrast sensitivity due to space flight. The VFT-2 series was conducted by Lt Col O'Neal and Dr. Lee Task over a seven-year period ending in late 1992.

VFT-3 was intended to be a color vision testing device to explore astronauts' comments regarding apparent changes in their color vision while in orbit. However, the requirements for the device to be self-administered, sufficiently accurate to assess small changes in color vision, battery powered, and space qualified proved too difficult, resulting in the abandonment of the device in the late 1980s.

VFT-4, the final vision testing device in this series, was designed to investigate the changes in visual near and far points and speed of visual accommodation (focusing) due to microgravity. This vision test was inspired by some astronauts' stories that they had difficulty reading in orbit and had to use their reading glasses, whereas they used their reading glasses optionally while on Earth. Lt Col Gerald Gleason was the primary force in getting VFT-4 manifested for flight on STS 59 during April of 1994 for its maiden space flight. It is hoped that data will eventually be obtained on a total of ten astronauts before concluding VFT-4 flights and this series of vision tests.

In the late 1980s, the Military Man-In-Space program became interested in the previously rejected out-cabin vision experiments. This led to the development of SpaDVOS (Spaceborne Direct View Optical System) which was basically a six-to-one zoom telescope that could be mounted to the aft flight deck overhead windows for convenience in steering the telescope. In addition, SpaDVOS provided a cueing display to help steer astronauts to specific pre-planned points of interest. Several people worked on the development of SpaDVOS, including Dr. Lee Task, Capt Harold Merkel, Capt Jim Whiteley, 1st Lt Pete LaPuma, Capt Scott Hoskins (from HSC), and a multitude of personnel from the University of Dayton Research Institute and Systems Research Laboratories. SpaDVOS was flown on two shuttle missions. During the first mission it was manually steered, and, on the second, it was upgraded to a motorized steering mode. The objective was to compare the level of visual information extraction possible through the telescope with the visual performance of the observers as measured by VFT-1. There was also interest in simply determining what level of visual information could be extracted in this manner in a real-time fashion. The results indicated the biggest problem limiting visual information extraction was the stability of the imagery due to difficulty in smooth tracking.

FIGURE 1-11: ENGINEERING RESEARCH SIMULATOR
Concept demonstrations of advanced controls and displays are evaluated in multi-operator environment. (Workunit 71841045)

B-52/B-1/B-2 Systems Integration and Design Evaluation

As mission requirements change, and with the advent of new technologies, changes to existing weapon systems and addition of new subsystems are necessary to implement new mission capabilities. In the traditional crew system design process, the operator has been treated as a slack variable which could be exploited to overcome deficiencies in design. In today's complex weapon systems, it is imperative that the operator, as a subsystem, be considered explicitly on an equivalent level with, and developed concurrently with, other subsystems (avionics).

The Crew Station Integration Branch of the Human Engineering Division has pursued a research program seeking to balance the development of human systems integration assessment technologies with their applications to real-world problems. Drawing on the operational and scientific and technical expertise of a series of military branch chiefs [Maj Lonnie Roberts (B-52 Pilot), Lt Col William Marshak (Psychologist), Lt Col Michael Eller (B-52 Radar Navigator), and Lt Col James LaSalvia (B-1B Offensive Systems Officer)], the branch has strived to combine a high degree of operational relevance with valid human engineering practices. Two major forces that have impacted the branch's research and development program are reduction in crew size (from the six-place B-52, to the four-place B-1B, to the two-place B-2) and evolution of systems-of-systems architecture by the warfighters (Figure 1-11).

Beginning with a two-place defensive station, made up of an Electronic Warfare Officer and Gunner, the conversion of surplus training assets into highly flexible research simulation facilities was successfully demonstrated by Earl Sharp. This approach preserves the accuracy of display and control arrangement and feel, while facilitating integrated performance and workload measurements. Simulation facilities for the B-52, the B-1B, and the B-2 aircraft were developed and employed by Earl, Brad Purvis, Gil Kuperman, and other branch members in support of emerging operational requirements. These facilities were complemented by the development of the Strategic Avionics Battle management Evaluation and Research (SABER) simulation facility, which was specifically built to support exploratory development. SABER, conceived and guided by Gil and Denise Wilson, is unique in that it can be used to simulate a generic, multi-place aircraft (bomber, tanker, transport, gunship) or, with a different software load, can support exploration of Battle Management/Command, Control, Computers, Communications, and Intelligence (BMC4I) decision-making functions.

The branch research program has explored the impacts on crews of integrating advanced avionics into existing and maturing aircraft platforms (led by the above individuals and 1st Lt Mike Stratton, Maj Ed Fix, Capt Marie Gomes, Dr. June Skelly, Dr. Mike McNeese, Capt Stu Turner, Capt Scott Smith, 1st Lt Lawrie Hamacher, and 1st Lt Stephanie Lind), the human-centered design issues associated with a surviving/enduring mobile command post (Denise Wilson), and the validation of conceptual human-system integration designs (Brad, Earl, Gil, Scott, and Stu). The Crew Station Integration Branch has been highly successful in application research based on a simulate-before-you-fly risk and cost reduction philosophy. Laboratory research has been complemented by the active participation of branch personnel in field and flight demonstrations. These projects include the investigation of night vision goggles for the B-52 and B-1B aircraft, the integration of night vision sensors and target cuers for navigation and target acquisition aiding, and the investigation of crew/vehicle interface requirements for a single-stage-to-orbit hypersonic spaceplane.

The recent research emphasis in the Crew Station Integration Branch is on exploring the impact on crews caused by integration into the manned bomber fleet of gravity and precision-guided conventional weapons, the integration of on-board mission management avionics, and the integration of real-time intelligence into the cockpit capabilities. Innovative research paradigms are currently being developed which tightly couple rapid prototyping technologies to man-in-the-loop capabilities.

2. Design Tools, Methods & Technologies

The Human Engineering Division studies human adaptation to increasingly severe operational challenges and develops databases, methodologies, tools, and standards to help system designers take maximum advantage of human capabilities and limitations in the design and evaluation of complex human-systems. This includes data concerning perception, human performance, and the multi-dimensional size, shape, strength, and functional characteristics of humans. The objective of this activity has been to assist the acquisition community in the design, specification, and testing of Air Force weapons systems. The approach, described in more detail below, has been to provide information for design engineers that permits them to integrate human operators into systems in a manner that will maximize total system effectiveness.

Integrated Perceptual Information for Designers

Reliable data on human ability to acquire and process task-critical information is of prime importance to the design of effective human-system interfaces. While the research literature contains an immense volume of pertinent data, it has not been systematically considered in the typical design of human-systems. Though the nature and availability of these data are a key part of this problem, this lack of utilization can also be attributed to the basic skills and inclinations of designers, limitations in the available support environment, and constraints imposed by the design and acquisition processes. Beginning in 1980, a series of US/NATO AGARD-supported efforts directed by Dr. Kenneth R. Boff were initiated to aid the use of ergonomics data in system design. The goals of these efforts have been to (1) identify and consolidate ergonomics data of potential value; (2) "human engineer" the representation of these data to enable their effective use by designers; (3) sponsor training to sensitize designers to the value and application of ergonomics; and (4) develop media options for aiding designers in the access, interpretation, and application of ergonomics data. These efforts at understanding and remediating problems in the transition of ergonomic research to applications have since coalesced into a new model for the communication of ergonomics data to practitioners, educators, and researchers. These efforts are summarized below.

Handbook of Perception and Human Performance: Attempting to use the research literature can be a formidable task. This is due, in part, to difficulties in retrieving and interpreting specialized data from the multitude of information sources distributed widely over a variety of report media. The first effort was to identify, collect, and consolidate performance data into a primary reference—the *Handbook of Perception and Human Performance* edited by Boff, Kaufman, and Thomas and published by John Wiley and Sons in early 1986. For this effort, a team was assembled made up of more than 60 recognized experts in 45 subareas of sensation, perception, information processing, and human performance.

Engineering Data Compendium: The objective of this effort was to speed up the transfer of human performance data to the designers of complex human-operated systems. The target users were system designers with little prior training and experience with ergonomics but with a need for reliable data to resolve trade-offs between equipment requirements and human performance capabilities. The product of this effort was a reference document, the *Engineering Data Compendium*, edited by Kenneth Boff and Janet Lincoln and published jointly by AAMRL and NATO in 1988. The Compendium provides comprehensive information on human capabilities and limitations, with special emphasis on those variables which affect the human's ability to acquire, process, and make effective use of task-critical information. Information was selected for inclusion into the Compendium on the basis of its practical potential for system design through an iterative process of review and analysis employing hundreds of subject matter experts and design professionals. Prospective entries were reviewed on the basis of statistical and methodological reliability, applicability to the normal adult population, and potential relevance to design problems.

Ergonomics in Design Short Course: A series of specially designed short courses and workshops were conducted with the goal of providing design professionals with strategies for the use of ergonomics data. These courses were designed around hypothetical, but realistic, human-system design problems which the individual lecturers and student teams systematically addressed in a workshop format. In 1986, this course was successfully offered overseas in Lisbon, Portugal; Athens, Greece; and Delft, Netherlands under the sponsorship of NATO AGARD.

Crew System Ergonomics Information Analysis Center (CSERIAC): In 1988, CSERIAC was established at Wright-Patterson Air Force Base, operated by the University of Dayton Research Institute, and managed by the Fitts Human Engineering Division. Crew system ergonomics information focuses on human and equipment characteristics that either enhance and support, or degrade and debilitate, human performance and well-being in complex tasks and activities. Over the past seven years, CSERIAC has actively supported research, design, and development of complex human-operated systems through on-call analysis and evaluation of ergonomics data and technology. Additionally, it has successfully accelerated the transfer of behavioral, biomedical, and engineering research to practical applications in the private and public sectors. It is presently under the expert administrative management of Dr. Lew Hann and Miss Tanya Ellifritt.

Computer-Aided Systems Human Engineering: Over a decade of research and development aimed at understanding and remediating problems in the transition of ergonomic data and models to application in the design of complex human-operated systems eventually coalesced into a new model of Computer-Aided Systems Human Engineering:Performance Visualization System (CASHE:PVS). CASHE:PVS version 1.0 was developed as a multimedia ergonomics database on CD-ROM for Apple Macintosh computers for use by human-system designers, educators, and researchers. Co-developed by a consortium of US Government agencies and NATO AGARD and managed by Donald Monk, it allows users to rapidly access ergonomics data and models stored electronically as text, tables, graphics, and audio. It contains a hypertext version of the Boff & Lincoln (1988) *Engineering Data Compendium*, MIL-STD-1472D, and a unique, interactive simulation capability: the Perception & Performance Prototyper (P3). P3 aids users in interpreting and applying ergonomics to their specific problems by enabling them to manipulate and directly experience alternative representations of the conditional variables associated with the archived data. The CASHE:PVS CD also features the state-of-the-art in information retrieval, browsing, and navigation (Figure 1-12).

FIGURE 1-12: CASHE:PVS
The ergonomics design tool, CASHE:PVS, integrates interactive testbenches, audio, and animations, with text, tables, and illustrations so that designers can explore and experience the perception and performance data which are described in its reference documents. (Task 718412)

Anthropometric Modeling

The performance of Air Force aircrew members and support personnel is directly influenced by the man-machine interface. To optimize this interface, highly accurate anthropometry is required to define the shape and contour of the human body. As the Air Force's sole source of expertise in anthropometry, the Human Engineering Division provides state-of-the-art measuring techniques and novel statistical methods which optimize the integration of Air Force equipment and weapon systems to the human.

COMBIMAN is an interactive 3-D ergonomic computer graphics model of a human seated at a work station. It models male and female physical characteristics and was developed in the Human Engineering Division as an engineering tool for evaluating capabilities and spatial accommodation of the operator. In 1978, it was first transferred to aerospace industries. By 1994, much progress had occurred in COMBIMAN technology, and development commenced on creating a Virtual COMBIMAN that places a display viewer inside a 3-D cockpit drawing during vehicle landings. Thus, virtual COMBIMAN (Figure 1-13) is an application of virtual reality technology.

The development of CREW CHIEF (Figure 1-14), another expert anthropometric computer model and ergonomic engineering tool, this time for a maintenance technician, began in the division in 1984 in collaboration with the AF Human Resources Laboratory. An interactive 3-D computer-aided design (CAD) human-model of an aircraft maintenance technician, CREW CHIEF was developed by Dr. Joe W. McDaniel for use by aerospace manufacturers in designing crew station configuration. CREW CHIEF was interfaced with industry computer-aided design systems and, in 1988, it began to be widely used in the aerospace industry to evaluate equipment maintainability.

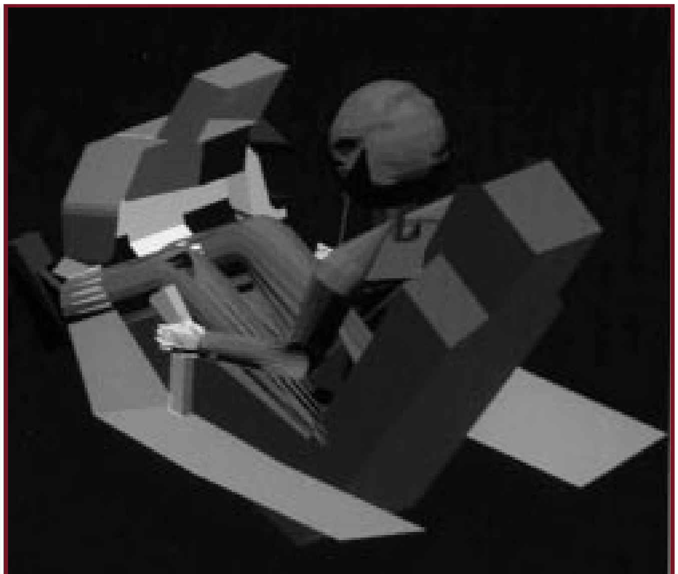


FIGURE 1-13: COMBIMAN
COMBIMAN creates a 3-D human model (male or female) together with six types of clothing, personal protective equipment, and three types of harness restraints . The user has full control over the size and proportion of the model, together with several computer-aided methods. Methods for incorporating the multivariate test sets, described above, are just one of many ways to dimension the model. Built in are models of male and female USAF pilots, non-pilots, and male and female Army pilots, per the latest 1988 survey. Strength analysis includes stick, wheel, lever, pedal, and ejection controls. Reach analyses consider clothing and harnessing for both reach to a specific control or a reach envelope (McDaniel, J.W., 1990). (Task 718408)

The above research and development work in physical anthropometry by personnel of the division's Physical Ergonomics Laboratory is only a small sample of the work done there in taking measurements of human physical dimensions, reach capability, strength and endurance, reaction time, time to perform tasks, etc. The laboratory has massive databases built on hundreds of thousands of measurements. These databases are often adequate for answering designers' questions. The Computer-Aided Workplace Design Facility of the laboratory is a network of computer work stations for developing and using expert ergonomics models, such as COMBIMAN, CREW CHIEF, and Virtual COMBIMAN, for visualizing physical performance in the workplace. When database entries and use of the computer models are inadequate for finding satisfactory answers for design questions, the rapid prototyping facilities of the laboratory allow it to quickly perform high-fidelity studies on task executions in work situations.

In the above discussion of physical anthropometry in the Human Engineering Division, it was noted that some of the technology of physical anthropometry, such as computer models, began in an earlier decade, and that development of the technology is still progressing. Figure 1-15 illustrates the chronology of important events, landmarks, and accomplishments in workplace technology resulting from the last 50 years of research and development work performed by the Human Engineering Division.

Engineering Anthropometry

The last decade has witnessed major technological leaps in the field of engineering anthropometry, and the Human Engineering Division has been at the forefront. The biggest innovations were in the areas of database systems, advanced statistical methods and applications, and 3-D anthropometric data collection.

Previously, the hundreds of anthropometric data collections were stored on shelves of magnetic tapes. During this decade, these were transformed into collated, searchable files on-line, and were made available off-site through modems. They were also integrated with statistical analysis tools that would enable the data system to actually write some of the analysis code. This work is still evolving with the development of object-oriented database software that will allow data to be stored and searched as objects, rather than individual elements, and with the rapidly changing Internet environments that are making information available to a much wider audience in forms easier to understand, visualize, and manipulate. This holds incredible promise for the next decade.

Analytic methods for anthropometric multivariate data representation, which were previously available only to the advanced statistician, were taken into the cockpit. Since the 1960s, gross errors, which resulted from the use of percentiles, had been demonstrated but remained in common use due to the complexity of alternative approaches. Figure 1-16 illustrates one of the problems with the

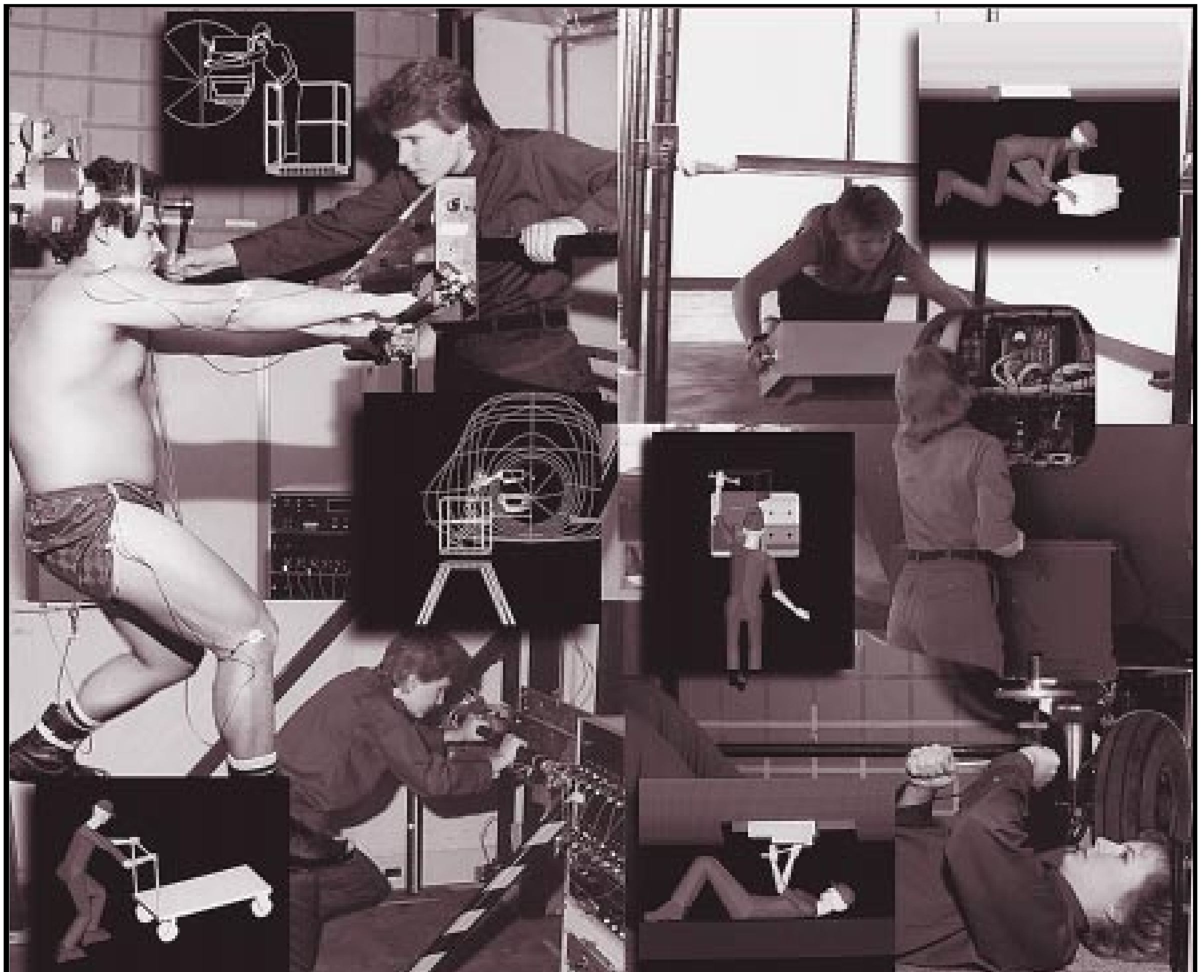
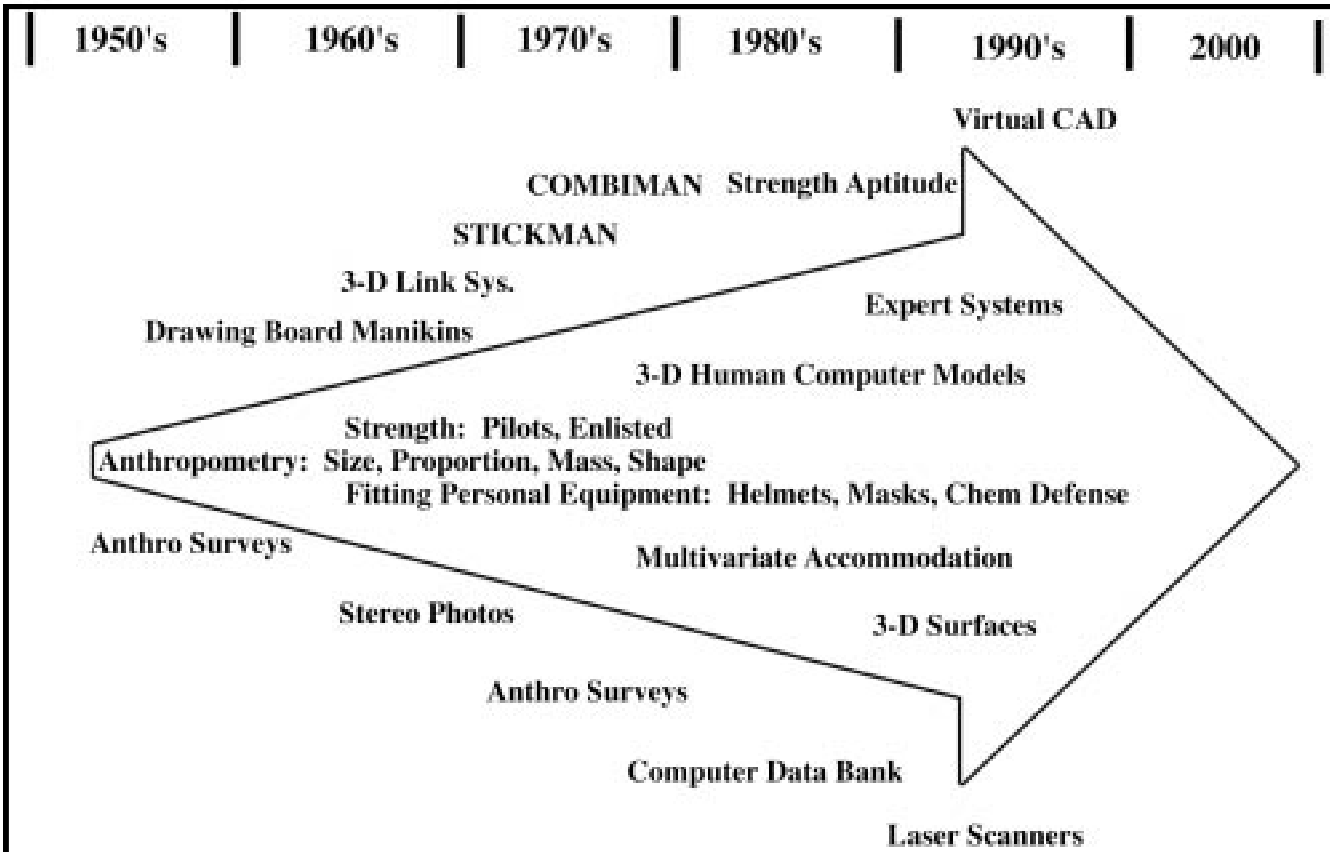


FIGURE 1-14: CREW CHIEF

CREW CHIEF, derived from COMBIMAN, automatically simulates maintenance activities, both with hand tools and materials handling (lifting, pushing, carrying, etc.), to determine if a maintenance activity is physically possible. Expert system software creates the 3-D human model with a full range of body sizes for men and women, the encumbrance of 4 types of clothing, 12 different maintenance postures, and a 222-piece tool kit. It automatically analyzes physical access for reaching into confined areas (with hands, tools, and objects), visual access, and strength. Visibility and task interference analyses can be computed with this "electronic mock-up" (Annis, J.F., McDaniel, J.W., & Krauskopf, P., 1991). (Task 718408)

use of percentiles and the magnitude of the impact from their use. As each new variable is designed or limited to just the 5th to 95th percentile, more and more people fall outside the accommodation range. The people who are extremely large or small for one variable are not the same people who are extremely large or small for another. Therefore, the more percentiles you use, the fewer people you accommodate. The purpose for using percentiles was to accommodate a particular percentage of a population. For example, the 5th and 95th percentiles were used with the intent of accommodating 90 percent of the population. This figure demonstrates that this is clearly not the case.

Greg Zehner, in 1992, demonstrated a practical implementation of an alternative multivariate approach, using principal component "cases" to evaluate cockpit accommodation. One of the first applications was in the acquisition of the T-1 aircraft. This acquisition was to be an "off-the-shelf" purchase, and manufacturers supplied their candidates for evaluation. After the multivariate anthropometric evaluation, it was determined that the otherwise best candidate would not accommodate 30 percent of white males, 80 percent of black males, and 90 percent of females who would qualify for flight training in the configuration presented. The cause was determined to be a problem with the



50 Years of Workplace Accommodation Technology

1946 - Strength for Aircraft Controls first measured in Paul Fitts division
1950 - Body size survey of 4,000 male pilots, 146 dimensions
1950 - 2-D Drawing Board Manikins depict range of body sizes for designers
1955 - 3-D Link System developed, relations between external flesh and internal joint centers defined
1957 - Masses of body segments for acceleration and crash test research
1958 - Stereo photography used in 3-D body size measurements
1959 - First general sizing system for flight clothing
1965 - Body size survey of 1,905 Air Force women, 139 dimensions
1967 - Body size survey of 2,420 male flight crew, 189 dimensions
1972 - STICKMAN is first human mel (stick figure) applied to first-generation computer-graphics displays
1974 - Strengths for aircraft control measured on centrifuge during high acceleration
1975 - COMBIMAN development began, 3-D computer model of aircraft pilot
1978 - COMBIMAN first transferred to aerospace industries
1978 - Female strength for operating aircraft controls first measured
1980 - Anthropometric relations with body segment masses and moments of inertia
1984 - CREW CHIEF model of maintenance technician began; interfaced to industry CAD systems
1987 - Strength Aptitude Test for all enlisted recruits approved by Secretary of Air Force
1988 - 3-D coordinates of head surface with laser scanner
1988 - CREW CHIEF first transferred to industry, began widespread use to evaluate maintainability
1988 - CARD dial-up body size database: Computerized Anthropometric Research Data
1994 - Virtual COMBIMAN Phase 1 puts viewer inside 3-D cockpit drawing during landing; variable sitting height
1995 - Multivariate accommodation technique used to evaluate JPATS trainer aircraft prototypes
1995 - Comprehensive male/female strength for all types of aircraft controls

FIGURE 1-15: WORKPLACE ACCOMMODATION

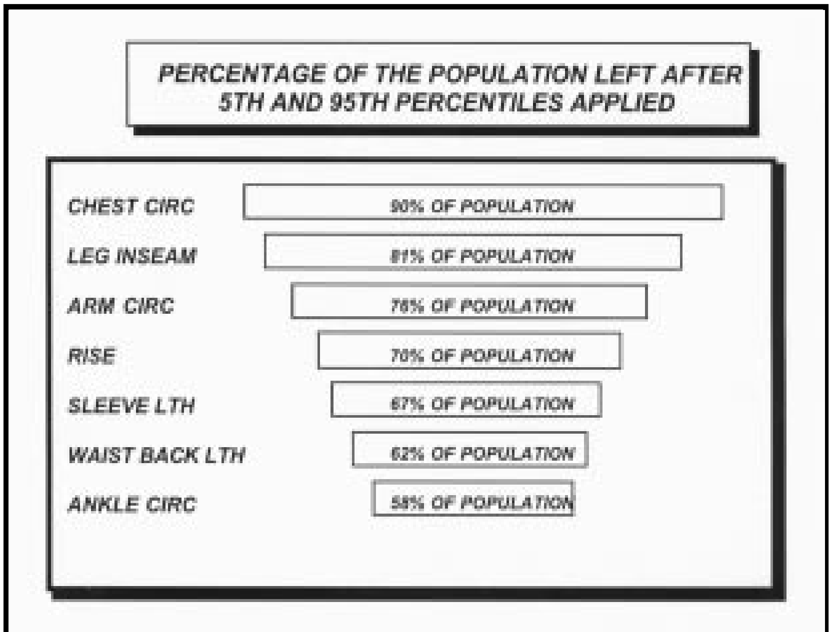


FIGURE 1-16 PERCENTILE VALUES
An illustration of the reduction in accommodation with each additional application of percentile values. (Task 718408)

yoke throw. This is pictured in Figure 1-17. This problem is manifested in those people who have short torsos and long legs or short torsos and large thighs. These represent combinations of small and large measurements which could not be characterized with percentiles and, thus, would not have been detected if only percentiles were used. In fact, we were told that the aircraft was designed for the 1st to 99th percentile pilot, and the manufacturer fully expected to accommodate at least 98 percent of the white male population. Since black males tend to have shorter torsos and longer legs than white males, and females tend to have shorter torsos and larger thighs than males, these groups were most affected.

That story ended well. Having identified the cause, the multivariate method also helped to identify the solution. The manufacturer was able to reconfigure the yoke to accommodate 99 percent of all of the eligible pilot populations.

Once the success of the multivariate approach for eligible pilots was demonstrated, the next question became, "who should be eligible pilots?" With Congressionally mandated policy changes on women in combat, the multivariate accommodation method began to be employed to evaluate accommodation beyond the former entry limit standard of 64-78 inches in stature and 34-39 inches in sitting height. This impacted the requirements for the Joint Primary Aircrew Training System (JPATS) Program, and anthropometric accommodation became one of the two highest selection criteria for that aircraft. Anthropometry, a term few people knew in the last decade, was for the first time being debated by Congressional staffers.

These developments were new and exciting, but perhaps the greatest change from the previous decade was the development and use of new automated 3-D surface scanning technologies for anthropometry. Some three-dimensional anthropometric data, collected prior to the mid-1980s, can be classified as two types: 1) measurement of a finite set of “homologous” points either statically or during motion, and 2) measurement of detailed points on static bodies. The former type of measurement requires a clear definition of all homologous points to be measured, referred to as landmarks, prior to measurement. On static objects, these points were measured mechanically by moving a stylus to each of the pre-defined (and often pre-marked) points and recording the stylus position. For example, Snyder, in 1972, used moveable scales and plumb bobs to record points on cadavers. Reynolds and Leung, 1983, implanted targets in unembalmed cadavers which were then captured with x-rays in stereo pairs. Gordon et al., 1988, used a mechanical stylus with a computerized 3-D locator for head measurement of living US Army personnel. A head box with a special clamp was used to steady the head as the stylus was moved from point to point.

Detailed 3-D measurement was limited to methods which did not automatically translate to geometric information, but rather the geometry had to be somehow manually extracted. One such method is stereo-

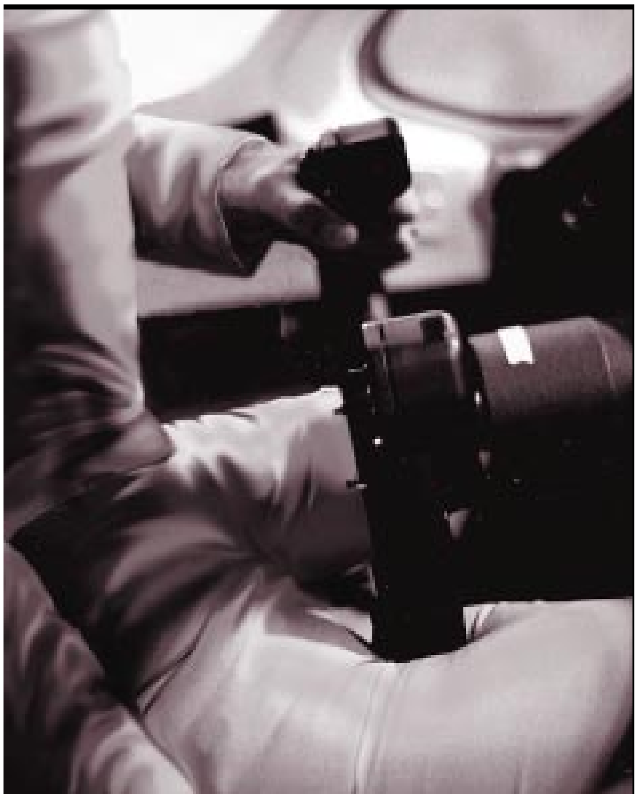


FIGURE 1-17: YOKE INTERFERENCE
Photograph of a pilot with yoke interference in the prototype T-1 aircraft. (Task 718408)

photography. Stereophotogrammetry basically captures the exterior surface with linked pairs of photographs. While it captured the images rapidly, the manual digitizing of the images was extremely slow. As a result, the number of subjects digitized in any one study was small; one set of studies which used stereophotogrammetry for estimating mass distribution properties of body segments measured just 31 men and 46 women.

New automated digital scanning technologies began appearing in the 1980s. The first one to be put to practical use was a head and face scanner produced by a company called Cyberware. Cyberware had developed a scanner for making realistic busts, much as portrait photographs are taken. It wasn't until they were approached by the anthropometry group at the Human Engineering Division that they considered it as a potential measurement tool. The anthropometry group worked with Cyberware to modify it for this purpose, adding a calibration tool and supporting software, for example. By 1987, the first head and face 3-D survey was completed at Wright-Patterson Air Force Base by the anthropometry group. In 1988, the scanner was taken on the road to three Air Force bases. This system is now the system against which others are compared. A photograph of the scanner is shown in Figure 1-18.

Automated 3-D scanning surmounts several problems inherent with the use of traditional anthropometry. For example, a nearly infinite number of contours can be derived from the traditional measurements; therefore, items produced by different manufacturers meeting the same anthropometry specifications can produce very different products in terms of shape and, ultimately, fit. In other words, due to anthropometry limitations, most of the surface of human models in the past has been filled in by artistic interpretation. This is true for ergonomic models such as COMBIMAN, CREW CHIEF, MANNEQUIN, SAMMIE, and JACK; biodynamic models such as ADAM and VIP; clothing body forms; oxygen masks; face forms and head forms for helmets. Furthermore, recent helmet fit testing has revealed that human surface geometry data

FIGURE 1-18: 3-D SCANNER
The automated 3-D scanner used in the first anthropometric scanning survey. Developed under a program managed by Kathleen Robinette, it was responsible for changing the field of anthropometry worldwide. (Workunit 71840850)

and the 3-D geometric link to the equipment are essential for understanding the underlying cause for fit problems and for quantifying and correcting them. As a result, knowledge of contour geometry can be critical to the success or failure of an equipment system. With the new automated 3-D scanning technology, it is possible to quantify the person and the equipment in 3-D space for the first time.

This new technology also makes it possible to exploit the power of new rapid prototyping and custom manufacturing technologies. For example, in 1995, a program was initiated to develop an automated method for producing custom-fit, positive-pressure oxygen masks. The ability to make prototypes quickly will reduce development costs by eliminating risk factors early in the design process. The ability to custom fit equipment will maximize accommodation levels, allowing accommodation of virtually 100 percent of a population. It can also reduce inventories and the cost of developing sizes for small percentages of the population. If effective, it can save billions of dollars.

The advantages of 3-D scanning are clear, and, in 1995, the Human Engineering Division acquired the first practical full-body 3-D scanning system and is planning the first international 3-D full-body survey. This will be a modern technology version of the NATO survey conducted by Mr. Hertzberg and associates in 1960-61. In the next decade it can be expected that this information, software tools, and application methods will be available on the information superhighway.

Crew-Centered Cockpit Design

Until the early 1980s, the laboratory did not have advanced development projects with which to demonstrate and mature its basic research and exploratory development products. The previous decade witnessed the emergence of high-technology sensors, weapons, and aircraft, which posed serious cockpit workload and safety concerns. The era also commenced a trend toward fewer crew members to lower acquisition cost, but that further aggravated the workload and safety concerns. Some systems emerging from flight test evidenced considerable cockpit-related design problems, requiring costly rework late in development. Senior Air Force leaders recognized that the Air Force lacked an advanced development project to focus the needed technology for the future (Figure 1-19).

In March 1980, the Air Force Systems Command directed the Air Force Laboratories to plan a new advanced development project for cockpit design technology. In response, a multi-laboratory working group (under a steering group comprising all AFSC Laboratory Commanders) planned the new project up to the point of a command decision to proceed. During the planning phase, the Air Force Studies Board (AFSB) convened a summer study at Woods Hole, MA in 1981 on "Automation in Combat Aircraft." The AFSB was an advisory group to the Commander of the Air Force Systems Command and comprised nationally renowned experts who made recommendations on topical issues. The 1981 summer study concluded that the Air Force should establish an advanced technology project to better organize how crew systems should be developed. The Studies Board met again in February, 1982, at Wright-Patterson Air Force Base, reaffirmed the summer study conclusions, recognized that the Air Force lacked an advanced technology project to focus this technology, and the AFSC Commander directed that the project be funded. Originally named Cockpit Automation Technology, the work was assigned to the Armstrong Laboratory and Human Engineering Division in 1982. The project was later renamed Crew-Centered Cockpit Design (CCCD).

The CCCD Project seeks to advance the state-of-the-art in crew system design technology, both for the process of design and for the tools that support the design process. The main products of the CCCD development are its highly disciplined process for cockpit design and a complete set of support tools and technology that will help to make the process efficient. Spanning all phases of system acquisition from concept exploration through production and deployment, the CCCD process is implemented on a computer design system having an integrated set of computer tools for crew system analysis, design, and test. Crew-centered cockpit design represents a new capability for human systems integration, one that is compatible with and improves upon the current design practice. By designing the cockpit with the crew capabilities as the central focus, CCCD can maximize the air crew's ability to meet the challenge in future air operations.

In its first decade, the CCCD project directly influenced the way that crew systems are designed and acquired, in the aircraft industry and in DOD's acquisition and test agencies. Five of the nation's aircraft manufacturers participated in CCCD research and development contracts and continue to organize their crew system projects from a crew-centered focus. For example, Boeing replicated a version of CCCD's computer design system for use on its military aircraft projects, and McDonnell Douglas continues to maintain its own Advanced Crew-Centered Technology Project. Both are evidence of technology transition. The CCCD project published the first-ever industry survey of the cockpit design process and tools. The CCCD project participated in the F-22 development through a Memorandum of Agreement, contributed to its cockpit specification, was part of the System Program Office (SPO) Cockpit Working Group, and CCCD's crew-centered mission scenarios were the models for the design missions used in the F-22 demonstration/validation phase. The CCCD project advanced the recommendation to raise the reporting level of Crew System Development in the Work Breakdown Structure. The F-22 SPO, departing from tradition, adopted the idea and elevated its crew system team for better management visibility and influence. CCCD's published work on the organization of the design process both in industry and government was the model for the design process and detailed Crew System Engineering Master Schedule, both codified in MIL-STD-1776A, thereby affecting all future Air Force cockpit acquisitions. A particularly successful part of the CCCD project is its Test Planning, Analysis, and Evaluation System (Test PAES), now completing operational tests at more than 20 flight test agencies, including all of the USAF Combined Test Forces, Army and Navy test centers, and non-DOD customers, supplying an entirely new test and evaluation support capability for planning and performing cockpit evaluation.

3. Innovative Human System Interfaces

Visually-coupled, helmet-mounted technologies allow aircrews to operate in day or night environments, providing essential flight attitude and targeting information which permits off-bore sighting of weapons and sensors. Improvements in image intensifier technology will allow for the demonstration of Night Vision Goggles (NVGs) with a 60-degree field-of-view in 1995. While NVGs serve a

FIGURE 1-19: THE CREW-CENTERED RECONFIGURABLE COCKPIT
Control, monitor and record real-time part-task, full-mission simulation. (Project 2829)

wide range of aircrew applications, the helmet-mounted display (HMD) that provides head-up display (HUD) symbology, forward-looking infrared (FLIR) and low-light level TV (LLLTV) imagery, or simple targeting cues, has a place in the high-performance cockpit as well as special operations aircraft. Critical technologies in the areas of three-dimensional audio localization, miniature video displays, and head trackers essential to an integrated helmet-mounted system were under development during this period.

Night Vision Operations and Aircraft Transparencies

The Human Engineering Division had its first exposure to night vision goggles in 1977, when it was loaned a pair of PVS-5 NVGs by then Major Robert Verona of the US Army for evaluation in possible Air Force applications. Two years later, in 1979, Human Engineering Division scientists, Dr. Lee Task and Leonard Griffin, were fully prepared to respond to the Military Airlift Command's request for assistance in modifying their HH-53H Pave Low III helicopter interior lighting to be NVG-compatible for the first time ever, thanks to the experience gained with the loaned PVS-5 NVGs.

This was the beginning of an expanding series of night vision operations projects, in direct support of a multitude of Air Force and Army NVG users, that came to full fruition during the 1985-1995 decade. Night Vision Operations activities have resulted in nine US Patents, with six other NVG-related inventions in patent-pending status. Under the expertise, innovativeness, and technical guidance of Dr. Task, there were numerous significant accomplishments during this time frame involving several key personnel. These include the developing, testing, and fielding of an NVG-compatible covert landing aid for landing cargo aircraft in austerely lit, potentially hostile environments (1982, Leonard Griffin); an NVG symbology overlay display, NVG-HUD, allowing the pilot to maintain an "eyes out" orientation during flight thereby decreasing workload and increasing mission safety and effectiveness (1982-1983, Leonard Griffin and Jeff Craig); low-profile NVGs offering a better center of gravity for paratroopers and possible aircraft ejection capability (1986, Jeff Craig); portable covert runway/taxiway marker lights for use with NVGs in both fixed and rotary wing aircraft (1987, Jeff Craig); NVG resolution charts for pre-flight optimization of NVG focusing (used in Operation Desert Storm-1990, Mary Donohue-Perry); NVG measurement methodology for assessing and validating NVG performance (1990-1995, Pete Marasco and 1st Lt Rich Hartman), a night vision ambient illumination tester for use in the laboratory or field to assess the degree of illumination present in a proposed NVG operating environment (1994, Dr. Alan Pinkus); and wide field-of-view NVGs offering a tremendous increase in the intensified night viewing area (1995, Jeff Craig) (Figure 1-20). Numerous other NVG-related human performance studies, aircraft lighting modifications, and technical consultations positioned the Human Engineering Division as one of the major forces in successfully transitioning night vision technology into Air Force operations.

During the early 1970s, the F-111 aircraft converted from thin glass windscreens to thicker plastic windscreens to improve birdstrike resistance. With this conversion came numerous new visual characteristics (Figure 1-21) of the thicker plastic windscreens, causing potential visual problems for the aircrew. Optical/visual windscreen analysis started at Brooks AFB, Texas, but, by the mid-1970s, transitioned to the Human Engineering Division. Initial activity centered around the visual problems identified with the F-111 conversion, which included multiple imaging, distortion, and haze. Multiple imaging was particularly disturbing during night landings in that the pilot would see two sets of runway marker lights due to the multiple reflections within the new plastic windscreens. Means of characterizing this effect and others are among the major accomplishments of the Human Engineering Division windscreen group during this time period (key personnel included Dr. Robert Eggleston, Lt Col Lou Genco, Dr. Lee Task, Bill Kama, Capt Mike

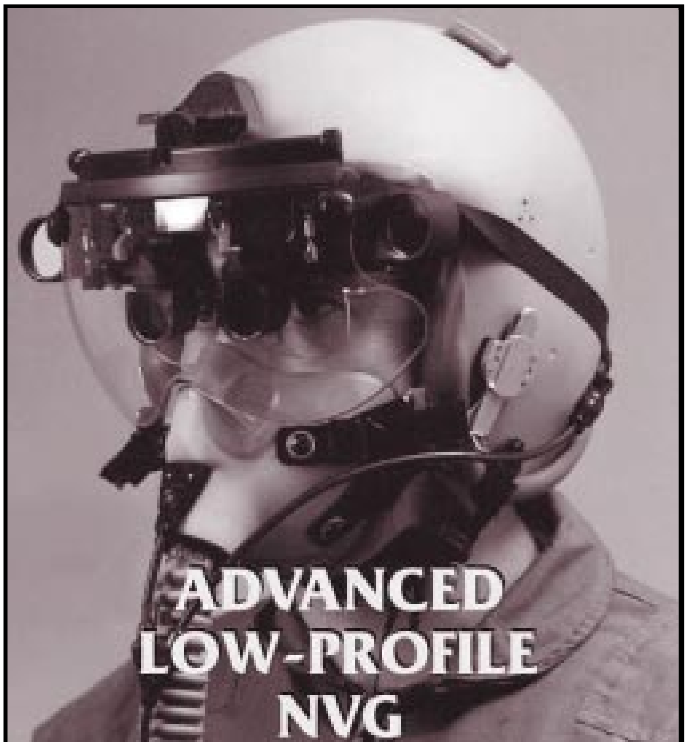


FIGURE 1-20: ADVANCED LOW-PROFILE NIGHT VISION GOGGLE (NVG)
Combining unique folded optics with high-resolution image intensifiers has resulted in a high-performance, ejection style NVG with a wide 45-degree field-of-view. (Task 718418)

Tutin, John Bridenbaugh, Harold Merkel, Dr. Alan Pinkus, and Pete Marasco). Standardized test methods for multiple imaging, distortion, haze, angular deviation, binocular disparity, reflection, and transmission were developed and published through the American Society for Testing and Materials (ASTM) for easy availability to both military and civilian applications. A total of twelve US patents, three other inventions still pending, and numerous human performance studies, presentations, publications, and consultations to both military and civilian organizations characterized this highly productive, successful program.

Visually-Coupled and Visual Display Systems

In this technology area, design criteria, component technology, and systems for visually-coupled helmet systems (VCHS) are developed on the basis of psychophysical theory and human performance data obtained in laboratory studies and on functional assessments during field evaluations under operational conditions. The state-of-the-art for VCHS was advanced by improved optical system and electronic circuit designs, hardware, and associated software. These improvements impact the performance and applicability of helmet display systems both militarily and commercially and allow research into the man-machine interface (MMI) to be pursued further than previously possible. Virtual display system component technology developments have been pursued under the Virtual Panoramic Display (VPD) program for transition to industry and the Armstrong Laboratory's Helmet-Mounted Sensory Technologies (HMST) 6.3A Advanced Development Program.

The Visual Display Systems Branch of the Human Engineering Division of the Armstrong Laboratory has played the key role in the development of helmet-mounted displays and sights and of visually-coupled systems. This technology is now used in many aircraft weapon systems and, increasingly, in other applications, both military and civilian. The division involvement dates from the mid-60s when Dr. Thomas Furness, Dean Kocian, James Brindle, and Charles Bates, of what is now the Visual Display Systems Branch, foreseeing the potential of the technology for improving the performance of military aircraft, initiated a program lasting decades to extensively develop it (See Table 1-3).

Over the past decade, the lab has focused on critical system and component tests and human factors experiments to solve the problems of integrating helmet-mounted display systems with the human visual system and advanced weapons systems. As evidenced by the many premier accomplishments shown in Table 1-3, the lab's research results have been successfully employed to optimize helmet-mounted display and miniature CRT phosphors, gun designs, and cathodes by investigating binocular vision, resolution, and contrast perception.

Dr. Brian Tsou led both equipment engineering research and human factors efforts involving the relationships between binocular helmet display design and visual performance of the human operator. In particular, he conducted research on binocular

TABLE 1-3 - Integrated Visually-Coupled Systems (VCS)/Night Vision History (29 Years of Armstrong Laboratory (AL) Leadership)*

YEAR	EVENT
1966	- First Remote HMS Development Inaugurated to Slew Sensors on B-50 Test Aircraft (Code Name: JB50).
1967	- Miniature CRT and HMD Development Initiated.
1968	- JB50 HMS System Accepted and Made Operational.
1969	- JB50 System Installed and Successfully Tested in Navy F-4B at Point Mugu NAS for Radar and Weapon Seeker Slaving Using Head LOS. - HMT and HMD Combined to Form First VCS (Precursor to All Subsequent Virtual Reality Systems). - HMS Pointing and Tracking Accuracy Study Initiated by AL at Tyndall AFB, FL F-101 and F106B aircraft.
1970	- First Direct Interface of HMS with Infrared Seeker Missile (AIM-4D) in F-106B with Live Fire Drone Shots and Kills Using Head-Slaved Seeker. - First Take-Offs and Landings Using Windowless Cockpit and HMD-External Camera Only Performed in F-100 at Kelly AFB, TX.
1971	- Visor Reticle Display for HMS Successfully Demonstrated by AL. - Advanced HMT Technology Development Begun by AL Involving Ultrasonic, Infrared, and AC Magnetic Technologies. - VCS Interface Successfully Demonstrated with Maverick Electro-Optical Seeker Head Prototype. - First VCS LOS Steering of Aircraft Using Head Motion Demonstrated by AL Personnel in C-131 Aircraft. - Tyndall AFB HMS Accuracy Tests Successfully Completed Resulting in Special Report ADC 69-19.
1972	- Visor Reticle Display and Infrared Tracker Technology Successfully Transitioned to Navy for Use in F-4 Retrofit Program. - Aiming of Aircraft Weapons Using HMS Demonstrated in C-130 Gunship. - Advanced HMT Technology Program Completed with AC Magnetic Approach the Clear Winner. - Program 5973 (Advanced Technology Demonstration) for Airborne-Qualified VCS Initiated. (Would later be Transferred to Aeronautical Systems Center in 1975) - First-Ever VCS Symposium Organized by AL and Held at Brooks AFB, TX. Papers Covered Head-Mounted Technology That Would Eventually Find Its Way Into Operational Use, as well as Virtual Reality Systems, Beginning in the Mid-1980s.
1973	- First Successful Visor-Projected Imagery Display Demonstrated for HMD Application. - First Successful Remote Oculometer System Demonstrated by AL Personnel. - Big Picture Concept Formulated. Essentially, the Concept was to Place Most of the HUD Information on the HMT/D System, Allowing the HUD to be Down-Sized, and Permitting Room in the Cockpit for Large Area Displays that Interacted with the HMT/D and Could More Effectively Present Global “Strategic” Information While the HMT/D Provided the Pilot with Near-in “Tactical” Information. - VCS Concepts Demonstrated With Long-Range Electro-Optical Seekers in Pave Scope at Edwards AFB, CA.
1974	- First-Ever Head-Steered Laser Designation Demonstrated in Pave Spike Program Using F-4 at Eglin AFB, FL.

YEAR	EVENT
1975	- Visually-Coupled Airborne Systems Simulator (VCASS) Program Initiated. Concept Involved the Design and Fabrication of a High-Resolution, Wide Field-of-View (FOV) HMD with High Resolution, Six Degree-of-Freedom HMT to Provide Scene Simulation with VCS Interactive Graphics Interface Overlay. Precursor to Modern Virtual Reality Systems.
1976	- Infrared HMT, Model 3 HMD Optics and Miniature CRT Technology Successfully Transitioned to Army Apache Program. - Advanced Miniature CRTs Developed for Use with HMDs.
1979	- Wide FOV (100°-140°) Partially Overlapped HMD with Successful Distortion Correction Demonstrated by AL Personnel. - First-Ever Demonstration of NVG with Compatible Cockpit Lighting Demonstrated in HH-53H Helicopter.
1980	- AL Personnel Complete Landmark Study Involving Incandescent Versus Electro-luminescent Lighting for Austere/Covert Runway Lighting to Support Covert Flight Operations.
1982	- NVG-Compatible Lighting Installed in A-10, AC-130H, and MC-130E by AL Personnel. - First-Ever NVG/HUD Designed and Built by AL Personnel and Installed on C-141B. - First-Ever Infrared Approach Path Indicator Developed for NVG Landings. - Full-Up VCASS Virtual Reality System Completed and Demonstrated.
1983	- AL Personnel Install NVG-Compatible Cockpit Lighting into CH-3, HH-53B/C, C-103E, and HC-103P. - NVG/HUD Installed and Flight Tested by AL Personnel on C-130E, MC-130E, and AC-130E Aircraft. - Day/Night Aerial Refueling Patent Employing NVGs Issued to AL.
1984	- NVG/HUD Installed and Tested on UH-60A, HC-103P, HH-53H, and HH-53B/C. - Virtual Panoramic Display (VPD) Program Begun in Support of Army LHX Helicopter Program. Essentially This Program Would Develop, Build, and Demonstrate Advanced VCS Technology to Support the LHX Night Pilotage FLIR. - Advanced Subminiature CRT Program Initiated for NVG/HUD and HMD Application.
1985	- First-Ever Diffuse Incandescent Runway Marker Light for Overt/Covert Operations and Glide Slope Indicator Demonstrated and Receives Separate Patents. - Advanced Subminiature CRTs Demonstrated for Use in NVG. Become DeFacto Standard for Narrow FOV HMT/Ds.
1986	- First Low-Profile NVGs Developed and Demonstrated by AL. - First DC Magnetic HMT Developed and Demonstrated in F-16 Attached to Green Mountain Air National Guard in Vermont.
1987	- NVG and NVG-Compatible Lighting Developed and Installed in B-52. - Advance “Box-and-One” Covert Landing Developed and Demonstrated by AL.
1988	- Unique “Contrast Sensitivity Function Measurement Chart” and Method Developed, Demonstrated, and Patented by AL. - AL Develops First-Ever “Deceleration, Prefocus Lens” Miniature CRT Able to Maintain Nearly Constant Line Width Over Large Beam Current Changes. - VPD HMD Prototypes Demonstrated to US Army Personnel. - Vista Sabre I Simulation Study Completed and Demonstrated Advantage of HMT/D Used in Conjunction with High Off-Boresight Angle (HOBA) Missile Seeker in Fighter Aircraft.
1989	- First Ultra High-Resolution Sputtered Phosphor Screen Developed and Tested in Miniature CRT. - Army Downselects VPD HMD Prototypes, for Which it Wants Flyable Brassboard Versions Built.

YEAR	EVENT
1990	- NVG-HUD Installed and Tested in MH-60J. - NVG Resolution Chart Perfected and Fielded On Short Notice for “Desert Storm” Operation.
1991	- Unique Robust Minimum Variance Linear Estimator (MVLE) Developed and Demonstrated for AC Magnetic HMT. - Unique Personal Illumination Marker Built and Demonstrated. - Vista Sabre II Program Initiated to Install HMT/D Systems in Two F-15Cs Located at Nellis AFB, NV.
1992	- NVG-Compatible Lighting Designed, Installed, and Flight Tested in B-1 Bomber. - First-Ever Course Prepared and Presented at SPIE International Symposium. - Miniature CRT Aviation Connector (AVCON) Demonstrated, Which Greatly Enhanced HMT/D Performance and Supportability by Fighter Squadron Personal Equipment Personnel.
1993	- Agile Eye™ Plus HMT/D Systems Successfully Integrated and Flown in Vista Sabre II. - AL Personnel Help Navy Initiate Their Own Vista Sabre Program Using F-18 and F-14. - NVG Low-Profile (Concept VI) System Demonstrated. - Unique Ambient Illumination Tester for NVG Developed by AL Personnel. - Programmable Airdrop Infrared Decoy Developed and Patented. - World’s First Successful Mechanical High-Voltage, Quick-Disconnect Connector (QDC) for HMD Developed and Tested. - First “Standardized” Helmet-Vehicle Interface (HVI) Conceptualized. - World’s First Miniature Subtractive-Color LCD Image Source Demonstrated.
1994	- Field Evaluation of NVG-Compatible Lighting Designs Evaluated for C-17, F-22, F-16, and C-130H3. - Wide FOV (Up to 60°) NVG (NOVA-8) Demonstrated. - Liquid Crystal-Based NVG/HUD Developed. - Agile Eye™ Mark III HMT/D System Flown in F-15C at Nellis AFB with Joint USN/USAF Developed HOBS Captive Carry Missile Seeker. - AL VPD System Delivered to Army and Used to Demonstrate Army’s New High-Resolution LLLTV System at NVESD. - Visually-Coupled Acquisition and Targeting System (VCATS) Program Initiated to Develop Advanced HMCS for F-15C/D/E Aircraft.
1995	- Monochrome Field-Emitter-Array (FEA) Cathode Miniature Flat CRT Demonstrated. - Landmark Chapter on VCS Technology Written by AL Personnel and Entitled "Visually-Coupled Systems Hardware and the Human Interface," Published in Oxford University Press Book, *Virtual Environments and Advanced Interface Design*.

***NOTE:** Acronyms Used In Chart Are Explained Below.

VCS: Visually-Coupled System
NVG: Night Vision Goggles
HMT: Helmet-Mounted Tracker (head orientation and/or position)
HMS: Helmet-Mounted Sight (HMT plus fixed sighting display)
HMD: Helmet-Mounted Display (display only - doesn’t include HMT)
HMT/D: HMT plus HMD
NVG/HUD: NVG plus head-up display overlay viewed through NVG.
CRT: Cathode Ray Tube
HMCS: Helmet-Mounted Cueing System
LOS: Line-of-sight from head azimuth and elevation orientation.
HOBS: High Off-Boresight Seeker
HOBA: High Off-Boresight Angle

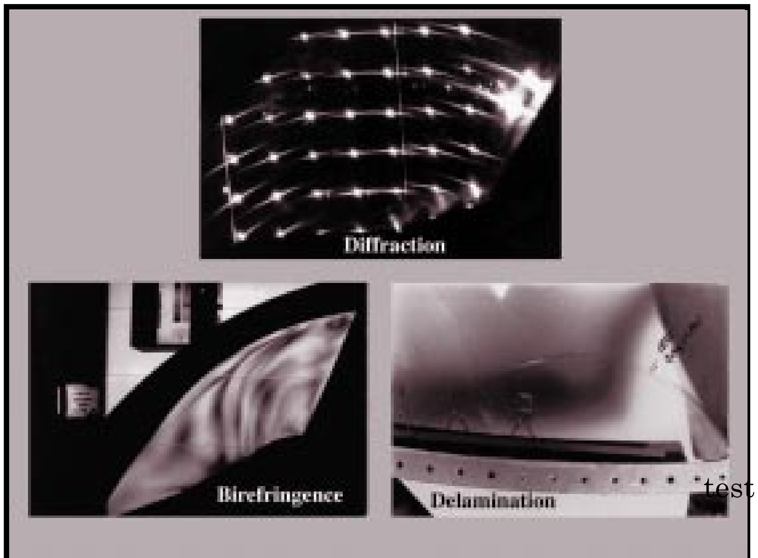


FIGURE 1-21: OPTICAL EFFECTS OF AIRCRAFT WINDSCREENS
Examples of some optical effects encountered in F-111 and B-1 aircraft windscreens. (Task 718418)

contrast sensitivity while using virtual image displays and generated binocular field-of-view requirements for the designing, building, and testing of next-generation, helmet-mounted displays. Two published studies have shown that the effective binocular visual field is about 40 degrees wide, and not the generally accepted number of 120 degrees, and that a divergent optics setup for overlapped binocular displays is superior to a convergent setup. Designers of Comanche helicopters have redirected their helmet-mounted display efforts to take advantage of these binocular vision research results.

The Visually Coupled Airborne Systems Simulator (VCASS) project directed by Dean Kocian began in 1977, as an effort to develop a fixed-base virtual environment simulator in which to investigate advanced airborne visually coupled concepts and their associated technologies. What set the Visually Coupled Airborne Systems Simulator apart from other fixed-base simulators was that all visual events within the simulation took place on a large field-of-view, partially overlapped binocular helmet-mounted display (HMD) that could generate 3-D stereo images and required special distortion correction to linearize the image viewed on the display. A six degree-of-freedom magnetic head tracker drove the scene presentation and allowed the parallax, due to head movements with respect to objects close to the observer, to be properly displayed. These advanced systems, when coupled with the wide field-of-view display system, resulted in a simulator that immerses the observer within an easily reconfigurable, computer-generated world, displayed relative to the observer's head movement (Figure 1-22). Since its initial demonstration, it has served as a test bed for investigating visually coupled display perceptual issues and the applied evaluation of candidate helmet-mounted display symbologies designed for specific tactical arenas. During the mid-1980s, Michael Haas successfully employed VCASS to demonstrate advanced rotocraft displays and interfaces for the Army LHX Helicopter Program. Later, Dr. Robert Osgood systematically employed VCASS in the research, design, and evaluation of off-boresight helmet-mounted symbologies with the goal of enhancing pilot performance by providing information about critical flight status, weapons systems, and warnings, regardless of head orientation or movement.

Color display design criteria development was led by Dr. David Post, through work performed at the Color Display Laboratory (CDL). The increasing performance and diversity, and decreasing cost, of electronic color display technology create new demands and opportunities for exploiting color's advantages for conveying information. Effective use of color requires knowledge of display capabilities and human needs. The primary emphasis of the CDL has been on the production of devices, software, data, and mathematical models relevant to the design, evaluation, measurement, and use of color displays throughout the Air Force. These efforts have produced a high-resolution and high-brightness prototype Miniature Color Display based on stacking three monochrome liquid-crystal displays together and operating them in a subtractive-color mode. The resulting Miniature Color Display provides daytime visibility with no resolution loss. Other products have included a high-efficiency, triband metal-halide lamp, a light-recycling pre-polarizer, and notch filter polarizers, all of which contribute significantly to the brightness of subtractive-color displays.

In 1993, the Vista Sabre II HMD Tech Demo Program retrofited two F-15Cs of the 57th Test Group at Nellis AFB with helmet-mounted display and head-tracker systems for the evaluation of high off-boresight weapon system use in an operational environment. Managed initially by Maj Vince Parisi and Dean Kocian and later by Randy Brown and Dean Kocian, Vista Sabre II began as a Congressionally mandated special project to evaluate and demonstrate the effective use of helmet-mounted cueing systems and symbology in “fast jet” combat aircraft. Inputs from the combat pilots at Nellis allowed the Visually-Coupled Acquisition and Tracking System (VCATS) Program to be inaugurated in 1994 as a top-ten ranked Advanced Technology Demonstration Program for Air Combat Command. VCATS will demonstrate advanced helmet-mounted tracker, image source, helmet technology, and perhaps most importantly, concepts for a “standardized” helmet-vehicle interface (HVI) that will promote commonality between USAF and USN fighter aircraft platforms.

Virtual Reality/Super Cockpit

One of the most challenging new technologies for application in the crew station is use of synthetic environments (SE), or what civilians call virtual reality. Capitalizing on two decades of helmet-mounted display work, SE has risen to the forefront in night operations which have been employed in Panama and Desert Storm. The simplest forms are the night vision goggles worn by aircrews. These will be supplanted by head-steered forward-looking infrared (FLIR) and later by multi-sensor systems that automatically switch or correlate their information. Hearing and touch will be brought into play with three-dimensional sound and tactile feedback. Controls will include helmet-mounted sights, such as in the Apache helicopter, and later, virtual switches actuated by tracking hand and finger motion through instrumented gloves. SE will provide “natural” user interfaces and the ultimate capability of tailoring the cockpit in both displays and controls to mission demands and user capabilities. Evolution of virtual reality, or synthetic environments technology, has been accelerated by the Human Engineering Division’s coordinated development of component technologies and the human engineering integration required of the overall system.

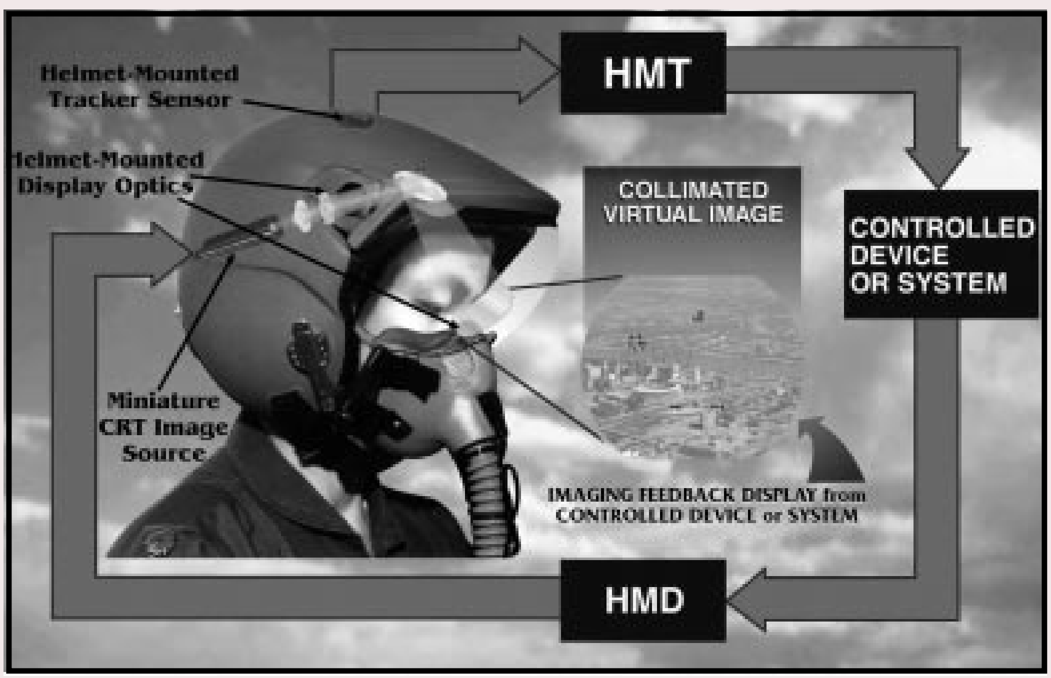


FIGURE 1-22: HMT/ HMD CONTROL AND FEEDBACK LOOP Combination of Helmet-Mounted Tracker (HMT) and Helmet-Mounted Display (HMD) forms a VCS with the human operator actively inserted into the control and feedback loop. (Task 718411)

FIGURE 1-23: CONCEPTUAL DRAWING OF COCKPIT OF THE FUTURE
This widely disseminated artist's conception is a graphic portrayal of a virtual situation head-mounted display system for an encapsulated tactical environment. (Task 718426)

The Super Cockpit Program was conceived under the visionary leadership of Dr. Tom Furness during Project Forecast II, which was an advanced planning exercise managed by the Air Force Systems Command in 1986. Dean Kocian, Michael Haas, and Dr. Robert Eggleston respectively, were selected to head up in-house hardware, software, and human factors R&D for the project. Dr. Wayne Martin played a key role in coordinating, managing, and documenting the myraid contacts and components of this complex R&D effort. The original concept was for "a revolutionary modular virtual crew station which communicates 3-D spherical awareness to the pilot or crew. Information from aircraft avionics, weapons, and sensors is fused, organized, and presented within a panoramic visual and auditory display surround for rapid assimilation by the pilot. The pilot directs weapons and commands aircraft systems by using line-of-sight, voice, and other natural psychomotor responses (Figure 1-23)". This program evolved into a 6.3 Advanced Demonstration Program, Helmet-Mounted Sensory Technology (HMST) presently managed by Randall Brown with Dean Kocian as Chief Engineer.

During Fall 1991, an international Super Cockpit program was formally initiated when the French and US Governments signed a Joint Memorandum of Understanding. The MOU involved three governmental organizations: the Human Engineering Division, Crew Systems Directorate of the Armstrong Laboratory at Wright-Patterson AFB; the CERMA in Bretigny, France; and the Section Etudes et Simulation, Centre D'Essais en Vol (CEV) in Istres, France. Nunn Amendment advanced development funding supporting the Super Cockpit Program began in December 1992. Dr. Kenneth Boff served as Program Manager and Michael Haas served as Technical Director and Chief Engineer.

The program was composed of two phases involving joint exploratory and advanced demonstration activity pursuing the design, development, and evaluation of control and display concepts utilizing multi-sensory, virtually augmented devices. The first phase consisted of the alignment of engineering research simulation facilities in the US and France. The second phase consisted of collaboration on the conceptual development and evaluation of virtually-augmented display and control concepts. During Phase One, Mike Haas, with the assistance of Chris Russell, directed the development of the SIRE Facility (Synthesized Immersion Research Environment) to create a synthetic environment for the rapid prototyping and evaluation of integrated virtual crew system concepts (Figure 1-24).

SIRE, which became operational in early 1994, consists of several autonomous research stations which can support individual research efforts or be combined to form a multi-participant virtual environment. One of the more striking research stations within the SIRE is a 40-foot diameter dome which includes a high-resolution, large field-of-view

FIGURE 1-24: SYNTHESIZED IMMERSION RESEARCH ENVIRONMENT FACILITY
SIRE facility (Synthesized Immersion Research Environment) provides a synthetic environment for research in visual performance, assessment of virtual design techniques, and the rapid prototyping and evaluation of integrated virtual crew system concepts. (Task 718419)

(70 degrees vertical by 150 degrees horizontal) interactive visual display driven by a Silicon Graphics Onyx computer image generator, with auditory displays capable of presenting simulated three-dimensional, externalized sound information, and an electro-hydraulic control loader system to provide augmented haptic cueing information. The Synthesized Immersion Research Environment lab is a general purpose research environment that can be configured to perform applied research on the design of advanced human-vehicle interfaces, including aircraft and ground vehicles. It can also be configured to perform more fundamental research on multi-sensory perception and human performance in virtual environments.

The VEIL (Virtual Environment Interface Laboratory) was founded by Dr. Robert Eggleston with the goal of providing technical data to characterize how humans perform in synthetic environments or utilize virtual devices in the performance of tasks. In support of the Super Cockpit program, Dr. Eggleston established bench-mark tasks that could be used to evaluate virtual system characteristics in terms of human performance applicable to a wide range of task conditions.

Alternate Control Technologies

Helmet-Mounted Oculometer System: In 1981, Michael Haas coordinated the receipt of residual equipment from Air Force Project 2360, managed by the ASD Simulator System Program Office. The key component of this delivery was a Honeywell helmet-mounted oculometer consisting of an infrared corneal reflection eye-tracking system and a magnetic helmet sight system. This delivery served as the impetus for a new research facility spearheaded by Dr. Kenneth Boff. The Helmet-Mounted Oculometer Facility (Figure 1-25) was established to capitalize on the Honeywell system's unique capabilities for unobtrusive and accurate monitoring of eye and helmet positions. In this regard, Mr. Haas managed the expansion of this residual equipment into a full-scale research facility, capable of measuring and recording eye and head data under experimenter-specified task paradigms.

Gloria Calhoun assumed responsibility for the Helmet-Mounted Oculometer Facility from 1983 to 1991. During the period, this facility examined the potential of using an operator's eye line-of-sight as an alternative control interface. Research determined the spatial/temporal parameters for implementing the eye-control algorithm and quantified the efficiency of eye control compared to other control mechanisms. Additionally, alternative eye monitoring techniques were evaluated in an effort to facilitate integration with visually-coupled systems and define performance parameters for airborne applications. The results of these research efforts paved the way for revolutionizing the interface between the pilot and aircraft. Use of eye control eliminates the need for a selective manual response by substituting the natural movement of the eyes which are inherent to the visual task. For tasks in which the pilot's attention is directed out of the cockpit, eye control could enable the control portion of these tasks to be completed with the head out of the cockpit.

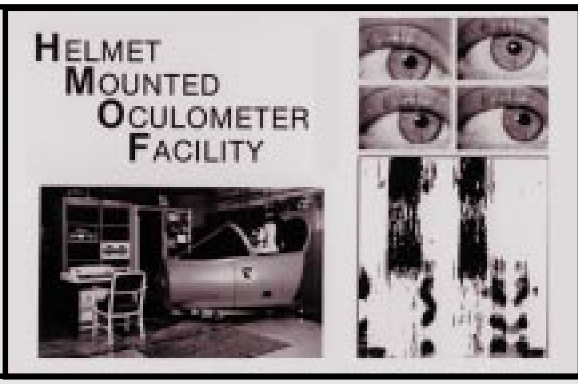


FIGURE 1-25: HELMET-MOUNTED OCULOMETER FACILITY
Both an eye tracker and voice recognizer were used to evaluate eye line-of-sight control with a verbal consent. (Workunit 71842602)

The Helmet-Mounted Oculometer Facility was also used during this time period to support other in-house research efforts. One was directed toward determining whether eye and head measures are valuable objective indicators of the effectiveness of attention cues and control/display design. Parameters of eye and head movements (e.g., sequence and latencies) were examined in comparison to the conventional performance index, manual reaction time, as a function of several factors: attention cue modality, task environment, attention allocation between tasks, and information location. In the case of cockpit design, this research suggests that these relatively nonobtrusive measures may be valuable indices for detecting a pilot's awareness of attention cues and changes in information presented. Another research effort examined the application of three-dimensional auditory signals to provide natural directional cueing. For example, the speed of target acquisition with a simulated aural directional cue was compared to conventional directional cues. The potential payoff of localized aural signals is the reduction in pilot workload together with an increase in situation awareness.

Brain-Actuated Control Research: This work grew out of research in the 1980s which examined the utility of the steady-state visual evoked response (SSVER) as an unobtrusive measure of cognitive workload. Subjects viewed a modulated light stimulus, and the brain response was evaluated as a function of the difficulty level of the primary task. Although this research did not show reliable sensitivity to task difficulty level, the variability in the SSVER data suggested that it was influenced by the subject's attentional state. To explore this further, a system was fabricated in 1987 to provide near real-time feedback on the EEG response to the evoking stimulus. The results of this closed-loop system still failed to show utility of the SSVER for workload measurement. However, subjects demonstrated their ability to regulate SSVER under various experimental paradigms, suggesting the exciting potential of using these brain responses as a direct link between mind and machine.

In 1989, Dr. Andrew Junker began to link the SSVER brain response feedback to a single-axis motion based simulator. Using biofeedback training, subjects learned to enhance or reduce the magnitude of their brain's response to a modulated light presented within a task display. These changes were then translated into commands that controlled the roll position of the simulator. The demonstration was a success, and subjects were able to operate the simulator using only brain-actuated control (Figure 1-26). However, it was evident control reliability and precision needed improvement before any application could be made.

In 1992, work resumed, under the direction of Maj Frank Fisher, to make significant system enhancements with the goal of improving signal acquisition and control efficiency. New control drive laws were developed for converting the brain response data into smooth, precise control signals. Ms. Gloria Calhoun assumed management of the effort in 1993, and directed the development of two new brain-actuated control task environments. In one, the brain-actuated control system was interfaced to a neuro-muscular stimulator, a device used to provide exercise for paralyzed limbs to illustrate potential rehabilitation applications of this innovative brain interface. In the second new task environment, subjects change the color of a displayed square to match the color of the square's border by modifying the magnitude of their brain response. This task environment is currently being used in an effort to investigate the neurological mechanisms of brain-actuated control. Efforts are also underway to explore the utility of a brain interface for aircraft related tasks, such as radio and radar operation. This may be especially useful during high-G and high workload conditions.

A key to Armstrong Laboratory's advancements in brain-actuated control is the support provided by Dr. Grant McMillan. As manager of the Alternative Control Technology Program, Dr. McMillan has provided support and technological insight for system improvements and research direction. Moreover, Dr. McMillan can be credited with the significant publicity which the brain-actuated control program has enjoyed, including features in PBS's *Scientific American Frontiers*, ABC's *Good Morning America*, and CNN's *Future Watch* programs. In addition, this research has been highlighted in many publications, including *Discover*, *Air Force Magazine*, *Air and Space*, and *The World and I.*

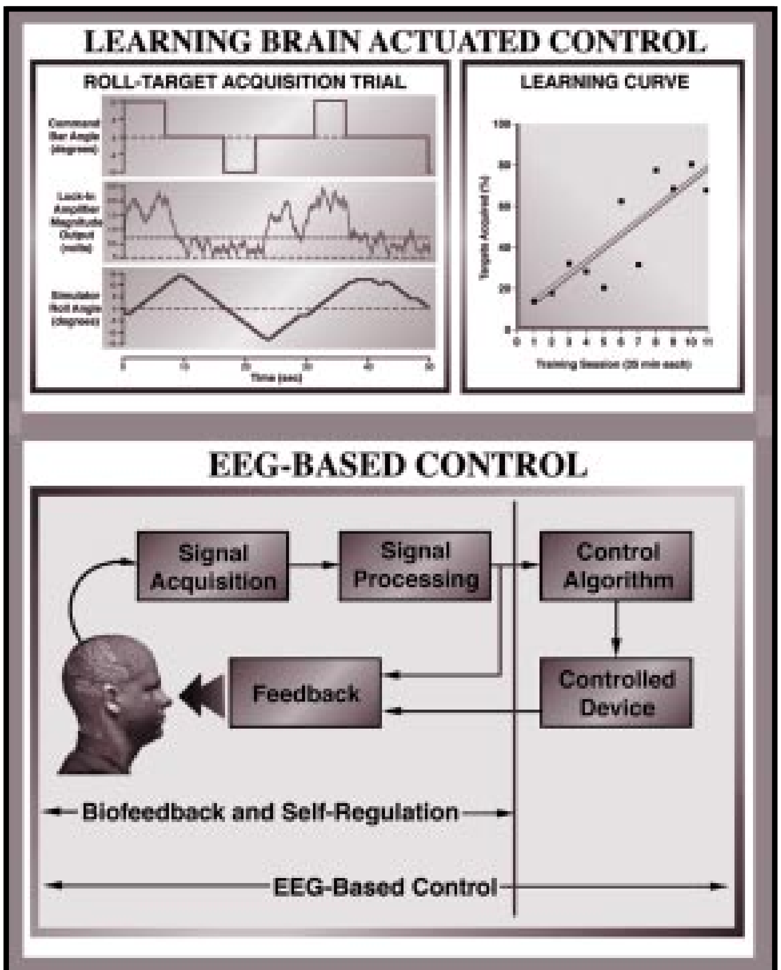


FIGURE 1-26: BRAIN ACTUATED CONTROL
Reliable EEG-based control of simulator roll angle achieved after four hours of training. EEG-based control is an extension of biofeedback methodology which translates EEG signals into control inputs. (Task 689306)

C. FACILITIES

In 1984, construction was completed on an extension to Building 248. This laboratory extension and accompanying modernization of the interior of 248 resulted in a doubling of available laboratory space to almost 70,000 sq ft. The resultant laboratory facility was primed to sustain its role as the pre-eminent human engineering research laboratory in the world. In 1985, the division was formally dedicated in honor of our founder as the Paul M. Fitts Human Engineering Division.

In January 1992, construction began on the Optical Systems Laboratory, a 200-foot long, self-supporting structure containing 14,500 sq ft of floor space joining Buildings 33 and 248 in Area B of Wright-Patterson Air Force Base. It contains five laboratories and has a horizontal window of special optical glass running its entire length, providing an unobstructed view to the West. Part of it is a structure resembling an airport control tower designed for tracking aircraft approaching the runway of Patterson Field in Area A. The tower facility will aid research in vision and the design and evaluation of helmet-mounted display systems, such as visually-coupled systems. It also has a spherical dome resembling a small observatory to be used for tracking aircraft and scanning the terrain. The new structure was completed in October 1993 (Figure 1-27).

D. ADMINISTRATION & MANAGEMENT

There can be little doubt of the value added from "50 Years of Human Engineering." The impact of our many technological successes and products has been felt and reported back to us from across the private and public sectors, around the country, and from many parts of the world. Less visible, but nonetheless a fundamental basis to these successes, have been the contributions of those professionals committed to the administrative and support functions of the organization. These include the branch chiefs, secretarial staff, technical editors, data processor managers, and administrators in accounting, contracting, personnel, travel, equipment, facilities, and support contracts. Though often unrecognized, these dedicated individuals collectively contributed greatly to the productivity, esprit de corps, and total quality of the divison and its products.

Take branch offices, for example. Made up of a branch chief and secretary, a successful branch office provides the full range of personnel, scientific, management, and support functions needed to allow branch members to be productive and to prosper. Branch chiefs generally are expected to split time between a full schedule of personnel duties and an equally full slate of technical duties—to be scientists, managers, leaders, motivators, disciplinarians, planners, and communicators. Secretaries, on the other hand, are expected to know how to do everything—and generally do. They are assigned a long list of duties, none of which captures the fact that they are primarily problem solvers and defacto assistant branch chiefs. Often they are the last link in the chain, the ones who get scribbled drafts at 3:45 P.M. that need to be in final form, coherent, proofread, and in ten copies by 4:00 PM. The finest secretarial work can easily go unnoticed because it tends to eliminate the problems and reduce the turmoil that normally command our attention.

The Human Engineering Division was graced over the last ten years, with a succession of branch offices of uncommon skill and effectiveness. The list below contains the names of prominent members of branch offices from that period arranged, roughly, by branch history.

Chiefs:	Secretaries:
Dr. Tom Furness Dr. Wayne Martin Lt Col Mel O'Neal Lt Col Mike Eller	Tanya Ellifritt Yolanda Crawford Theresa Schiavone
Capt Lee Penick Walt Summers	Cheryl Dunaway Rebecca Green Carole Patrick Sheila Radford Renee Kaffenbarger Anne Cato
Maj Lonnie Roberts Lt Col Bill Marshak Lt Col Mike Eller Lt Col Jim LaSalvia	Sharon Sain Tina Sanford Mary Louise Smith
Lt Col Lou Genco Lt Col Al Dickson Lt Col Mel O'Neal Dr. Grant McMillan Maj Ed Fix Maj Julie Cohen	Joanne Myers Laura Mulford
Maris Vikmanis	Marya Beverly
Dr. Clyde Replogle	Karen Unfried Betty Adams

The division office was equally blessed with gifted and tireless secretaries, including Barbara Osman, Suzanne Daly, and Betsy Combs. Each brought exacting standards to the job, thereby establishing and maintaining a tradition of business excellence. Their leadership has been invaluable.

Administration of the intangible resources entails personnel record keeping, budgeting, purchase request processing, expenditure tracking, STINFO, program and financial reporting, travel, manhour accounting, and several others. Originally administrated by the legendary Sandy Stevenson, these duties,

FIGURE 1-27: VARIOUS VIEWS OF THE HUMAN ENGINEERING DIVISION COMPLEX

swollen by ever-increasing reporting requirements, are now managed by the highly decorated, all-star team of Helen Redwine-Smith and Becky Green. The well-being of our tangible resources, e.g., our four primary buildings and their contents, was the responsibility of our real property managers, Al Chapin, SMSgt Dale Schimmel, and MSgt Bob Stewart. Each, during his tenure here, provided the Human Engineering Division with award-winning support. Two military construction projects and an in-progress, four-year infrastructure overhaul were handled with craftsman-like skill bringing the division's facilities in line with the finest in DOD. Mail distribution, travel orders processing, and similar duties were handled with dedication and superior know-how by TSgt Rob Johnson, SSgt Joe Gregory, and, more recently, SSgt Otis Newsome. A well deserved tip of the cap also goes to the really unsung heroes of the division--the managers of equipment and computer accounts, security, technical orders, hazardous material accounting, and many more.

Four contracts have provided broad technical support to the division over the last ten years. The largest, and most widely used, was held originally by Systems Research Laboratories (SRL), and now is held by Logicon Technical Services, Inc. (LTSI). During the majority of the ten-year span, these contracts were ably managed by Bob Linhart. With Bob's reassignment to another division in early Spring 1994, management responsibility passed to our professional engineer, Bob Centers. When Bob Centers retired, the contract was passed to 1st Lt Bryan Christensen. Each of these managers served with distinction, making this contracted effort a support cornerstone of the division's research program and a model for all DOD laboratories. Much the same can be said about the success of Tom Green, Don McKechnie, and 1st Lt Bryan Christensen as managers of the division's strategic systems support contract with Scientific Applications International Corp. (SAIC) over the same period. Though somewhat less active, the rapid prototyping contract, held first by the University of Dayton Research Institute (UDRI) and BDM Corporation, and more recently by UDRI alone, was skillfully let and managed by Randy Yates. It provided off-site engineering services in the rapid preparation of prototypes of human-system interface components in a form ready for evaluation, such as flight test. Somewhat different is the CSERIAC (Crew System Ergonomics Information Analysis Center) contract, also with UDRI, but let through the Defense Technical Information Center (DTIC). One of only a score of DOD information analysis centers, CSERIAC is sponsored by the Human Engineering Division and provides the international human engineering community with a center of excellence in ergonomics and a gateway to ergonomics information and expertise worldwide. This ambitious venture owes much of its considerable success to a cadre of Air Force personnel, including Dr. Lew Hann as Program Manager, Tanya Ellifritt as Program Administrator, and Dr. Kenneth R. Boff as Technical Director.

The use of computers in the Human Engineering Division has followed closely behind the state-of-the-art, though remaining just far enough behind to ensure system reliability and full functionality. The first computer "network" connecting all members of the division computationally was designed by Bob Centers, assisted by personnel of Systems Research Laboratories. The system was a mainframe-based structure which provided electronic mail, file transfer, bulletin boards, and access to ARPANET, on a VAX mini-computer. The overall ADPE, or automated data processing equipment, program was managed by Walt Summers. In the early 1990s, management of the ADPE program was transitioned to Randy Yates, under whose insightful and energetic guidance (with support from Logicon Technical Services personnel), the system progressed to a full local area network, or LAN. Today's LAN offers full office automation, an inexpensive microcomputer-based architecture, full compatibility between Apple and PC computers, access to Internet, and much more. In a companion effort, Bob Centers and Randy Yates, with participation from Al Chapin, MSgt Bob Stewart, TSgt Wiley Wells, and others, developed an ultra-modern multi-media room which combines state-of-the-art audio and video presentation capabilities under convenient and powerful computer control—a conference room of the future.